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SPECIFICATION

OPTICAL COMMUNICATIONS SYSTEM USING OPTICAL FREQUENCY CODES, AND OPTICAL TRANSMITTER, OPTICAL RECEIVER AND REFLECTIVE OPTICAL COMMUNICATION EQUIPMENT THEREFOR

TECHNICAL FIELD

[0001] The present invention relates to an optical communications system that utilizes the OCDM (Optical Code Division Multiplex), QPSK (Quadrature Phase Shift Keying), or QAM (Quadrature Amplitude Modulation) technique which multiplexes plural data sequences into a single data sequence that can be demultiplexed by use of different optical codes; furthermore, the invention pertains to an optical transmitter, an optical receiver and reflective optical communication equipment for use in the optical communications system.

Background Art

[0002] With respect to a point-to-multipoint transmission on the PON (Passive Optical Network) wherein two or more local offices are connected via optical fibers to a central office, there has been proposed a scheme according to which: each local office is assigned pseudo-random spreading codes orthogonal to each other, and modulates an optical signal in accordance with the spreading codes assigned thereto and transmits the modulated optical signal; and the central office multiplexes such optical signals from the respective local offices and transmits over a long distance. A description will be given below of a conventional technique for optical frequency coding in an optical frequency region by use of the spreading codes.

Fig. 1 schematically shows the configuration of one channel and

PROBLEM TO BE SOLVED BY THE INVENTION

[0006] The prior art disclosed in documents 2 and 3 refers to OCDM (Optical Code Division Multiplexing) in which data sequences are each assigned a wavelength selected with a different period equivalent to a code, but since these optical codes corresponding to each data sequence (channel) are not mutually orthogonal to each other, the code assignment in a narrow optical frequency width containing a small number of periods causes interference between the optical signals, resulting in a drop in their S/N (Signal/Noise). For example, letting the optical frequency difference to be assigned to the first data sequence and a reference optical frequency wavelength be represented by λ1 and λ0, respectively, a code is assigned to the first data sequence over a wide optical frequency width including not only one period of optical frequencies λ0 to λ0+λ1 but also multiple periods of optical frequencies λ0 to λ0+2λ1, λ0 to λ0+3λ1 ...; a code is assigned to the second data sequence over a wide optical frequency width including not only one period of optical frequencies λ0 to λ0+λ2 but also multiple periods of optical frequencies λ0 to λ0+2λ2, λ0 to λ0+3λ2 ...; and a code is assigned to the third data sequence over a wide optical frequency width including not only one period of optical frequencies λ0 to λ0+λ3 but also multiple periods of optical frequencies λ0 to λ0+2λ3, λ0 to λ0+3λ3 ...; and codes are similarly assigned thereafter. In this way, the prior art improves S/N.

[0007] With the above method, however, when the number of wavelengths to be selected with the period of a sine function is small, inter-channel interference between optical signals is not negligible, so that it is difficult to multiplex channel optical signals corresponding to many data sequences without degradation of the bit error rate. To suppress the inter-channel interference between optical signals, the frequency width of the light to be

hence it is better in information transmission efficiency than the equipment of non-patent document 3, but the central office sends a downstream optical signal of a low extinction ratio and the local office reuses the downstream optical signal of low extinction ratio for an upstream optical signal for information transmission. Hence, the downstream optical signal of low extinction ratio impairs the communication quality.

MEANS FOR SOLVING THE PROBLEM

[0009] The present invention has first through third aspects, each of which uses a function Ci(f) of an i-th code and its complementary function (1-Ci(f)), which satisfy the following conditions:

Function Ci(f) is a periodic function which satisfies Ci(f)=Ci(f+PFRi), and the function Ci(f) takes the value in the range of 0 to 1;

Optical frequency width FSR is an optical frequency width that is a natural-number multiple of the code length FCL which is a common multiple of a repetition period of the function of each code in the range from a predetermined optical frequency Fst to a predetermined optical frequency Fla;

The complementary function of the function Ci(f) is a function (1-Ci(f)) obtained by subtracting the function Ci(f) from 1, and the functions Ci(f) and (1-Ci(f)) bear the relationship $\int Ci(f) \cdot Ci(f)df > \int Ci(f) \cdot (1-Ci(f))df$, where $\int df$ is a definite integral with respect to f for an arbitrary interval FSR from Fst to Fla; and

Function Ci(f), a function Cj(f) of an arbitrary j-th code except an i-th one, and the complementary function (1-Cj(f)) of the function Cj(f) bear the relationship $\int Ci(f) \cdot Cj(f)df = \int Ci(f) \cdot (1-Cj(f))df$.

[0010] According to the first aspect of the present invention that is applied to optical code communication:

the transmitting side generates and transmits, for each piece of data of

a binary data sequence, an optical code signal whose optical intensity-frequency characteristic is at least one of the function Ci(f) and its complementary function (1-Ci(f)) both corresponding to the value of each piece of data of the i-th binary data sequence, at least over the enough wide period FSR that satisfies orthogonal relation between the functions; and

the receiving side regenerates from received optical signal a first intensity difference signal corresponding to the difference between a first intensity signal, corresponding to the optical intensity of an optical signal whose optical intensity-frequency characteristic is Ci(f) based on the function Ci(f), and a second intensity signal corresponding to the optical intensity of an optical signal whose optical intensity-frequency characteristic is (1-Ci(f)) based on the complementary function (1-Ci(f)); and regenerate the data sequence from the first difference signal.

[0011] According to the second aspect of the present invention which performs, for example, pseudo-orthogonal phase modulation:

and let Δf represent the remainder of the division of an arbitrary optical frequency width equal to or narrower than the optical frequency width FSR by the repetition period PFRi of the function Ci(f), let a phase 2π(Δf/PFRi) represent a phase difference from the function Ci(f), and let Ci'(f) (=Ci(f + Δf)) represent a function with an optical frequency (f + Δf) different by said remainder Δf from the optical frequency of the function Ci(f) of the i-th code, the function Ci'(f), the function Cj(f) and its complementary function (1-Cj(f)) bear the relationship:

$$\int Ci'(f) \cdot Cj(f)df = \int Ci'(f) \cdot (1-Cj(f))df;$$

the transmitting side separates a binary data sequence into multiple data sequences, then generates an optical signal whose optical intensity-frequency characteristic is at least one of the function and its

complementary function both corresponding to the value of each piece of data of each data sequence corresponding to each code and combines and transmits such optical signals as an optical code signal;

the receiving side detects, based on the functions corresponding to the above-said separated data sequences and their complementary functions, optical intensity differences between the optical signals having their optical intensity-frequency characteristics based on the above-mentioned functions, respectively, and regenerates the separated data sequences.

[0012] According to the third aspect of the present invention which is applied to reflective optical communication:

an optical signal whose optical intensity-frequency characteristic is the function Cj(f) or its complementary function (1-Cj(f)) is input at least the optical frequency width FSR, the input optical signal is input to an encoder whose filtering optical frequency characteristic is based on the function Ci(f) and which outputs an optical signal, and the input optical signal is input as well to a complementary encoder whose filtering optical characteristic is based on the complementary function (1-Ci(f)) and which outputs a complementary optical signal; and

optical signals and their complementary optical signals are selectively combined according to each piece of data of the input binary data sequence and transmitted as an optical code signal.

[EFFECT OF THE INVENTION]

[0013] According to the configuration of the first aspect of the present invention, the function Ci(f) is continuously repeated, and if it is within a frequency range from Fst to Fla, optical code signals of the optical frequency width FSR at an arbitrary position need only to be transmitted; therefore, even if a drift occurs in the optical frequency for the light source and the encoder of

show examples of light-source optical wavelength components, selection wavelength components of an encoder, its passage wavelength components, selection wavelength components of a decoder and its passage wavelength components;

Fig. 2 illustrates an example of the system configuration of a multiplex communications system to which the first mode of working of the present invention is applied, Figs. 2(a) and 2(b) showing its optical transmitter and optical receiver, respectively;

Fig. 3 illustrates another example of the multiplex communications system configuration to which the first mode of working of the invention is applied, Figs. 3(a) and 3(b) showing its optical transmitter and optical receiver, respectively;

Fig. 4 is a configuration illustrating an example of the communications system to which the first mode of working of the invention is applied;

Fig. 5(a) shows an example of a source frequency drift, Fig. 5(b) an example of an optical frequency region for encoding, and Fig. 5(c) an example of an optical frequency region for decoding;

Figs. 6(a), 6(b) and 6(c) are graphs showing examples of spreading codes in Embodiment 1, respectively;

Fig. 7 is a diagram illustrating an example of an encoder for use in Embodiment 1-2;

Fig. 8 is a diagram illustrating an example of a decoder for use in Embodiment 1-2;

Fig. 9 is a diagram illustrating an example of filters forming an encoder/decoder for use in Embodiment 1-2;

Fig. 10(a) is a diagram showing a first-order Hadamard matrix,

Fig.10(b) a diagram showing a second-order Hadamard matrix, and Fig. 10(c) a diagram showing a recurrence formula of the Hadamard matrix;

Figs. 11(a) and 11(b) are graphs showing examples of encoding codes (concatenated codes) corresponding to the second-order Hadamard matrix for use in Embodiment 1-3;

Fig. 12 is a diagram illustrating an example of a decoder for use in Embodiment 1-3;

Figs. 13(a), and 13(b) and 13(c) are diagrams showing, by way of example, source optical frequency component, optical frequency regions for encoding, encoded optical signals, optical frequency regions for decoding, and decoded optical signals in the cases where no source frequency drift occurs, and where the source frequency drift occurs, respectively, in Embodiment 1-3;

Fig. 14 is a diagram illustrating an example of a filter forming an encoder/decoder for use in Embodiment 1-3;

Fig. 15 is a diagram illustrating another example of the decoder for use in Embodiment 1-3;

Fig. 16 is a diagram illustrating another example of the filter forming an encoder/decoder for use in Embodiment 1-3;

Fig. 17 is a diagram illustrating still another example of the filter forming an encoder/decoder for use in Embodiment 1-3;

Fig. 18 is a diagram showing an example of a variable delay line for use in the filter forming the encoder/decoder in Embodiment 1-3;

Fig. 19 is a diagram showing another example of the variable delay line for use in the filter forming the encoder/decoder in Embodiment 1-3;

Figs. 20(a), and 20(b) and 20(c) are diagrams showing, by way of example, the relationships between source optical frequency component,

optical frequency regions for encoding, encoded optical signals, optical frequency regions for decoding, and decoded optical signals in the cases where no optical frequency regions for encoding drift occur, and where the source frequency and optical frequency regions for encoding drift occur, respectively, in Embodiment 1-3;

Fig. 21 is a diagram illustrating still another example of the filter forming the encoder/decoder for use in Embodiment 1-3;

Fig. 22 is a diagram illustrating another example of the encoder for use in Embodiment 1-3;

Fig. 23 is a diagram illustrating another example of the decoder for use in Embodiment 1-3;

Fig. 24 is a diagram illustrating another example of the encoder for use in Embodiment 1-3;

Fig. 25 is a diagram illustrating another example of the decoder for use in Embodiment 1-3;

Fig. 26 is a diagram illustrating still another example of the decoder for use in Embodiment 1-3;

Fig. 27 is a diagram illustrating a still further example of the decoder for use in Embodiment 1-3;

Fig. 28 is a diagram showing an example of an encoder/decoder combination according to the first mode of working of the invention;

Fig. 29 is a system configuration illustrating an example of the communications system to which the first mode of working is applicable;

Fig. 30 is a system configuration illustrating an example of the communications system according to Embodiment 2-1 of the second mode of working of the present invention;

Fig. 31 shows, by way of example, the relationships between the phase

corresponding to two values of piece of data and pseudo-carrier of a trigonometric function, Figs. 31(a), 31(b), 31(c) and 31(d) showing such relationships in the cases where the phase is 0, $\pi/2$, π and $3\pi/2$, respectively;

Fig. 32-1 is a diagram showing, by way of example, the relationships of the optical source output, a modulated output, a filtering characteristic, a filtered output at the receiving side and detected intensity to a 0-phase modulated output in Embodiment 2-1;

Fig. 32-2 is a diagram showing, by way of example, the relationships of the optical source output, a modulated output, a filtering characteristic, a filtered output at the receiving side and detected intensity to a $\pi/2$-phase modulated output in Embodiment 2-1;

Fig. 32-3 is a diagram showing, by way of example, the relationships of the optical source output, a modulated output, a filtering characteristic, a filtered output at the receiving side and detected intensity to a π-phase modulated output in Embodiment 2-1;

Fig. 32-4 is a diagram showing, by way of example, the relationships of the optical source output, a modulated output, a filtering characteristic, a filtered output at the receiving side and detected intensity a $3\pi/2$-phase modulated output in Embodiment 2-1;

Fig. 33 is a diagram illustrating an example of a phase modulation part 130 in Fig. 30;

Fig. 34 is a diagram illustrating an example of an optical transmitter in Embodiment 2-2;

Fig. 35(a) is a diagram showing an example of an optical transmitter in Embodiment 2-3, and Fig. 35(b) a diagram showing an example of a modified form of a modulator 132 in Figs. 35(a);

Fig. 36(a) is a diagram showing signal points on the coordinates in

QPSK, and Fig. 36(b) is a table showing the relationships of a data set, a coordinate point and a filter-selecting phase;

Fig. 37-1 is a diagram illustrating an example of an optical transmitter in the communications system according to Embodiment 2-4;

Fig. 37-2 is a diagram showing an example of an optical receiver for use in Embodiment 2-4;

Fig. 38(a) is a diagram showing signal points on the coordinates in QPSK, and Fig. 38(b) is a table showing the relationships of a data set, the filter-selecting phase and intensity to outputs from comparators 241 and 242;

Fig. 39 is a diagram illustrating another example of the optical transmitter for use in Embodiment 2-4;

Fig. 40 is a system configuration illustrating an example of a communications system according to Embodiment 2-5;

Fig. 41 shows examples of filtering characteristics in Embodiment 2-5, Figs. 41(a), 41(b), 41(c) and 41(d) showing the characteristics in the cases of where the phase is 0, $\pi/2$, π and $3\pi/2$, respectively;

Fig. 42-1 is a diagram showing, by way of example, the relationships of the optical source output, a modulated output, a filtering characteristic, a filtered output at the receiving side and detected intensity to a 0-phase modulated output in Embodiment 2-5;

Fig. 42-2 is a diagram showing, by way of example, the relationships of the optical source output, a modulated output, a filtering characteristic, a filtered output at the receiving side and detected intensity to a $\pi/2$-phase modulated output in Embodiment 2-5;

Fig. 42-3 is a diagram showing, by way of example, the relationships of the optical source output, a modulated output, a filtering characteristic, a filtered output at the receiving side and detected intensity to a π-phase modulated output in Embodiment 2-5;

Fig. 42-4 is a diagram showing, by way of example, the relationships of the optical source output, a modulated output, a filtering characteristic, a filtered output at the receiving side and detected intensity a $3\pi/2$-phase modulated output in Embodiment 2-5;

Fig. 43(a) shows an example of an optical frequency characteristic

function in the case where the chip number L = 24, P = 4, n = 1 and S = 6 in Embodiment 2-5, and Fig. 43(b) shows an example of the function in the case where S = 3 in the Fig. 43(a);

Fig. 44 shows, by way of example, the relationships of the chip number L, the phase shift amount P, a divisor S and Q and n in Embodiment 2-5, Figs. 44(a), 44(b) and 44(c) showing the relationships in the cases where

P = 0, P = 1 and P = 2, respectively;

Fig. 45 is a diagram illustrating an example of an optical transmitter according to Embodiment 2-8;

Fig. 46 is a diagram showing, by way of example, optical chips of each of S-chip light source in Fig. 45;

Fig. 47 is a system configuration illustrating an example of a communications system according to Embodiment 2-9;

Fig. 48-1 is a diagram showing an example of an optical transmitter in a communications system according to Embodiment 2-11;

Fig. 48-2 is a diagram showing an example of an optical receiver in Embodiment 2-11;

Fig. 49 is diagram illustrating the functional configuration of an embodiment of reflective optical communication equipment according to the third mode of working of the present invention;

Figs. 50(a) and 50(b) are diagrams showing examples in which chip functions are used as the optical frequency characteristics in the third mode of working of the invention, respectively;

Fig. 51 is a diagram showing an example in which encoders 440M and 440S in Fig. 49 have chip functions;

Fig. 52 is a diagram showing a functional configuration of another embodiment of the reflective optical communication equipment according to the third mode of working of the invention;

Fig. 53 is a diagram illustrating the functional configuration of an example of equipment according to the third mode of working in which transmitter and receiver circuits are both provided;

Fig. 54 is a diagram showing an example of the chip function in the third mode of working of the invention;

signals, which are input via optical fibers $18_1, \ldots, 18_N$ to decoders $12_1, \ldots, 12_N$, respectively, by which the original data sequences $D_1, \ldots, D_N$ are demultiplexed and decoded. The splitter 16 may be placed away from the decoders $12_1, \ldots, 12_N$ at different distances. The splitter 16 and the decoders $12_1, \ldots, 12_N$ may be disposed at the same place as shown in Fig. 3(b); it is also possible to employ a combination of the arrangements shown in Figs. 2(b) and 3(b).

[Embodiment 1-1]

Fig. 4 illustrates Embodiment 1-1 of the present invention in which the principle of the first mode of working of the invention is applied to a single-channel communications system. Embodiment 1-1 comprises, as is the case with the conventional optical communications system, a light source 10, an encoder 11, a decoder 12, and an optical transmission line (optical fiber) 13; furthermore, Embodiment 1-1 is provided with a dispersion compensator 17 that compensates for frequency-dependent propagation delay time differences due to frequency dispersion of the optical transmission line by leveling off delay times of respective frequency components of the optical code signal between its transmission and reception. The optical frequency bandwidth over which the dispersion compensator 17 implements compensation is broader than at least the optical frequency bandwidth of the optical code signal.

[0018] The light source 10 outputs an optical signal of an optical frequency width FSR corresponding to at least, in this example, the code length FCL (a common multiple of PFRi described later on) at least in the optical frequency region (from optical frequencies Fst to Fla) for encoding by the encoder 11. That is, in this example FCL = FSR.

An optical signal 20 emitted from the light source 10 is encoded by

the encoder 11 into an optical code signal in the optical frequency region. Unlike an encoder used in the conventional optical communications system

the encoder 11 for use in Embodiment 1-1 generates in the optical frequency region an optical code signal of the code length FCL which is equivalent to that of all encoding codes (code words) used in the optical communications system. The optical code signal in the above-mentioned optical frequency region has such properties as mentioned below. The intensity of an n-th optical code signal is a function Cn(f) of an optical frequency f (hereinafter referred to also as an encoding code); the function Cn(f) takes a value from 0 to 1; the integration value of the function Cn(f) for an interval of an arbitrary code length FCL (FSR in this example) in the optical frequency region from Fst to Fla for encoding by the encoder 11 is a value obtained by dividing FSR by 2; and the optical frequency characteristic of the light transmittance through the encoder 11_n is, in general, a repetition of the same function Cn(f) at intervals of the code length FCL in the optical frequency region from Fst to Fla for encoding by the encoder. And the following equations hold.

[0019] $Cn(f) = Cn(f+FCL) \qquad n = 1, \ldots, N \qquad (1)$

$$\int Cn(f) = FCL/2 \qquad (2)$$

In the following description an optical code signal whose optical frequency characteristic function of optical intensity is Cn(f) will also be denoted by Cn(f); that is, Cn(f) represents the optical intensity-frequency characteristic function, an n-th encoding code, or n-th optical code signal. The term "n-th (optical code signal)" corresponds to the term "n-th (optical code signal)" in other modes of working of the invention, and (function or encoding code) Cn(f)" corresponds to "(optical frequency characteristic function or code) Cn(f)" in other modes of working of the invention.

[0020] The decoder 12 for decoding the optical code signal generated by the encoder 11 in Embodiment 1-1 is such that for the n-th optical code signal Cn(f) the decoder 12_n continuously repeats generation of a function

(hereinafter referred to also as a decoding code) Dn(f) whose one period is equal to the code length FCL in the optical frequency region for decoding: Dn(f) is expressed by the following equation.

$$Dn(f) = Cn(f) - Cn'(f) \qquad (3)$$

where Cn'(f) is a complementary value of the optical intensity value of the n-th encoded code Cn(f), and a value of the function Cn'(f) is the complementary value of the function Cn(f); they bear the following relationship.

[0021] $Cn(f) + Cn'(f) = 1 \qquad (4)$

The scalar product of the value Cn(f) of the n-th optical code signal at the optical frequency f and the decoding code Dn(f) from the decoder decoding the n-th optical code signal is integrated with respect to the optical frequency f for a continuous optical frequency region corresponding to the optical frequency width FSR (FCL = FSR in this example) of the light source within each of the optical frequency region for encoding by the encoder and the optical frequency region for decoding by the decoder; the resulting value is a non-zero finite value FSR/4, which satisfies the following equation.

$$\int Cn(f) \cdot Dn(f)df = FSR/4 \qquad (5)$$

Incidentally, the integration of Eq. (5) is conducted over the optical frequency width FSR of the light source. FSR is just a natural-number multiple of the period FCL, but in this example FSR = FCL.

[0022] The scalar product of the n-th optical code signal Cn(f) and the decoding code Dm(f) from the decoder 12_n having decoded an m-th optical code signal Cm(f) other than the n-th optical code signal Cn(f), (where m=1, …, N and except for m=n), is integrated over the continuous frequency region corresponding to the optical frequency width FSR of the light source within each of the optical frequency region for encoding by the encoder and the

optical frequency region for

decoding by the decoder; the resulting value is zero, which satisfies the following equation.

$$\int Cn(f) \cdot Dm(f)df = 0 \qquad m \neq n,\ m = 1,\ \ldots,\ N \qquad (6)$$

As shown in Figs. 2 and 3, assume that the number of data sequences is a plural number N, that the first, ..., N-th data sequences are assigned first, ..., N-th encoding codes, respectively, and that the first, ..., N-th encoding codes are equal in their code length FCL. The optical frequency region for encoding by the encoder 11_n is set to be broader than the code length FCL of the optical code signal; the encoder 11_n generates and outputs the optical code signal Cn(f) in accordance with the data of the n-th data sequence by encoding, in the optical frequency region, the optical signal input from the light source and having the optical frequency width FSR, in this example, which is a natural-number multiple of the code length FCL. For example, when the data is "1" (mark), the optical code signal Cn(f) is output with one code length, and when the data is "0" (space), the optical code signal Cn(f) is not output. Incidentally, the mark and the space correspond to the one and the other of two kinds of modulation unit signals.

[0023] As will be seen from Eqs. (3) and (5), the decoder 12_n, which decodes the n-th data sequence from the optical signal having multiplexed thereinto optical code signals of the N data sequences, integrates the scalar products of the input optical code multiplexed signal and the n-th code signal Cn(f) and its complementary optical code signal Cn'(f), then detects the difference between the integrated values, and outputs "1" or "0" as decoded data, depending on whether the difference is equal to or greater than a predetermined value or smaller than the predetermined value.

As described above, in Embodiment 1-1, unlike in the prior art

example which uses a different wavelength period for each data sequence, the optical frequency width over which all optical code signals are orthogonal to each other is FSR (FCL=FSR) that is a natural-number multiple of the code length FCL, and the optical frequency characteristic of the transmittance of the encoder 11_n is such that Cn(f) continuously repeats in the optical frequency region from Fst to Fla for encoding by the encoder, and the optical frequency characteristic of the transmittance of the decoder 12_n is also such that Dn(f) continuously repeats in the optical frequency region Fst to Fla for decoding by the decoder; therefore, each optical code signal keeps the properties shown by Eqs. (5) and (6), and even if the position of integration on the optical frequency is changed, the integrated value of the scalar product of each optical code signal in the decoder remains unchanged. Accordingly, in Embodiment 1-1 if the optical frequency width FSR of the light source to be encoded is constant and the optical frequency width is included in each of the optical frequency region for encoding by the encoder and the optical frequency region for decoding by the decoder, the optical code signal emitted from the encoder corresponding to the light source having its optical frequency changed is received by the decoder as an optical signal of the same intensity as that of the emitted optical signal, and no increase will be caused in the interference between the other optical code signals which do not correspond to this decoder. For example, as shown in Fig. 5(a), the optical frequency width of the output optical signal from the light source 10 is f_{L1} to f_{L2}=FSR, and this optical frequency width is a natural-number multiple of the optical code length FCL over which all codes are repeatedly generated (1 being chosen as the natural number in this embodiment); this optical frequency width f_{L1} to f_{L2} is included in each of the optical frequency region for encoding by the encoder 11_n and the optical frequency region for decoding

by the decoder 12_n as shown in Figs. 5(b) and (c). Accordingly, even if the

optical frequency of the output light from the light source 10 drifts as indicated, for example, by the broken lines, as long as it stays within the optical frequency region for encoding and the optical frequency region for decoding, the optical code signal of the drifted optical frequency is decoded by integrating the input multiplexed optical code signal and the decoding code Dn(f) over FSR (equal to the code length FCL in this example) corresponding to the optical frequency width of the light source; this integration and the relationships given by Eqs. (1) and (2) ensure generation of the same decoded signal as is obtainable without the optical frequency drift, and suppression of an increase in interference. Similarly, even if the optical frequency region for encoding and the optical frequency region for decoding drifts, decoding can be achieved with high accuracy. The optical transmission bandwidth of the optical fiber for transmitting the combined optical code signal from the combiner 15 (see Figs. 2 and 3) needs only to be wider than the optical frequency width FSR of the light source to such an extent as to fully accommodate optical frequency fluctuations of the light source. The optical frequency region for encoding and the optical frequency region for decoding may also be the same as the above-mentioned optical transmission bandwidth. In other words, since codes are orthogonal to each other in the first mode of working of the invention, the optical frequency width FSR of the light source may be equal to the code length FCL of every code, in which case the optical frequency width necessary for transmission over the optical fiber may be an optical frequency width that is the sum of the code length FCL and an optical frequency fluctuation of the light source.

[0024] The prior art disclosed in document 2 uses the optical frequency width at which spreading codes are not orthogonal to each other, and requires, for canceling inter-code interference, a broadband light source that is used to

obtain optical signal

frequency, making it possible to avoid the necessity for calibration of the optical frequency of the output signal from the light source.

[Embodiment 1-2]

Embodiment 1-2 of the first mode of working of the invention is a specific operative example of Embodiment 1-1 and uses a trigonometric function as the encoding function C(f). In Embodiment 1-2, in the case of using the smallest possible and invariable value a (which is a positive integer) to generate r' codes, if the value a is taken as an integer value in the range of 1 to N/2 where N is the maximum number of codes (the maximum number of encoders) and if r is taken as 0 or 1 that is the remainder of 2, the n-th optical code Cn(f) is used which is expressed by the following equation.

[0026] $Cn(f) = (1 + \cos(2 \cdot \pi \cdot a \cdot f/FCL + r \cdot \pi/2)) / 2$ (7)

This optical code signal function Cn(f) takes a value from 0 to 1, and the value of integration of the code signal function for an arbitrary source optical frequency width FSR (FSR = FCL in this example) in the optical frequency region for encoding by the encoder 11_n is FSR/2; the optical frequency characteristic of the transmittance of the encoder 11_n is a repetition of the function Cn(f) with a cycle of its code length FCL in the optical frequency region for encoding by the encoder and satisfies the relations of equations (1) and (2).

[0027] In Fig. 6 there are shown examples of the optical code signal Cn(f) in Embodiment 1-2. The abscissa represents the optical frequency normalized with the code length FCL and the ordinate represents optical intensity; Figs. 6(a), 6(b) and 6(c) correspond to values a = 1, 2 and 3, respectively, and the

broken and solid lines indicate optical code signals corresponding to $r = 0$ and $r = 1$, respectively. The optical code signal is one that single frequency optical signals corresponding to respective chips, except for $Cn(f) = 0$, vary in intensity in analog fashion in order of their arrangement unlike the spreading code consisting of single-frequency optical signals of which values are each "1" or "0" corresponding to one of chips as shown in the Fig. 1 prior-art example.

Used as the decoding code Dn(f) of the decoder 12_n for decoding the n-th optical code signal Cn(f) is expressed by the following equation.

[0028] $Dn(f) = (1 + \cos(2 \cdot \pi \cdot a \cdot f/FCL + r \cdot \pi/2)) - 1$ (8)

The scalar product of the n-th optical code signal Cn(f) and the n-th decoding code Dn(f) for decoding the n-th optical code signal is integrated over a continuous optical frequency region corresponding to the light-source optical frequency width FSR included in each of the optical frequency region for encoding by the encoder and the optical frequency region for decoding by the decoder, the resulting value being a non-zero finite value FSR/4, and the scalar product of the n-th optical code signal Cn(f) and a decoding code Dm(f) of a decoder for decoding an m-th optical code signal other than the n-th one over a continuous frequency region corresponding to the light-source optical frequency width FSR included in each of the optical frequency region for encoding by the encoder and the optical frequency region for decoding by the decoder, the resulting value being zero; these values satisfy Eqs. (5) and (6) in Embodiment 1-1.

[0029] Fig. 7 shows an example of the configuration of the encoder 11_n for use in Embodiment 1-2. A Mach-Zehnder interferometer is used, as the encoder 11_n, which is made up of a pair of optical paths 41 and 42 of different optical path lengths and a pair of couplers 43 and 44 optically coupled thereto

for coupling and splitting their optical inputs into two which are fed to the

optical paths. The light input to the one input port of the coupler 43 is output via two output ports to the optical paths 41 and 42. At the one output port of the coupler 43 is mainly provided light of an optical frequency component spaced an integral multiple of a predetermined frequency interval apart from the optical frequency dependent on the optical path difference between the optical paths 41 and 42, whereas at the other output port is provided mainly the other optical frequency component. This optical frequency selecting characteristic is a gentle one, not ON-OFF-wise; therefore, for example, in Fig. 6(a) the selected (normalized) optical frequency is f1 and an optical output of a cosinefunction is provided whose intensity is 1 at the selected optical frequency f1.

[0030] Accordingly, the n-th optical code signal Cn(f) given by Eq. (7) is provided as an output A from the one output port of the coupler 44. From the other output port is provided an complementary optical code signal Cn'(f) as an output B.

Fig. 8 shows an example of the configuration of the decoder 12_n for use in Embodiment 1-2. A Mach-Zehnder interferometer 55 is used which is made up of a pair of optical paths 51 of different optical path lengths and a pair of couplers 53 and 54 optically coupled thereto; a combined optical code signal is input to the Mach-Zehnder interferometer 55, which provides, as an output A at the one output port, the n-th optical code signal Cn(f) given by Eq. (7), and the optical intensity of the output is detected as an electrical signal by a detector 56a. As the other output B from the Mach-Zehnder interferometer 55 is provided an optical code signal Cn'(f) that is an complementary version of the n-th optical code signal Cn(f) given by Eq. (7), and the optical intensity of the output Cn'(f) is detected by a detector 56b as an electrical signal. The output A corresponds to the scalar product of the input combined optical code

signal and the encoding code Cn(f), whereas the output B corresponds to the

emitting light over a period large enough to ignore inter-code interference, that is, the optical frequency bandwidth of the output light from the light source need not be wide, in particular, and the transmission bandwidth needs only to be wider than the optical frequency width FSR of the light source to such an extent as to accommodate optical frequency fluctuations of the light source; therefore, this embodiment permits suppression of waveform deterioration and limitations on the transmission bandwidth both attributable to wavelength dispersion on the transmission line.

[0032] Furthermore, in Embodiment 1-2, a $\pi/2$ phase shift of the optical code signal at the start position on the optical frequency axis, that is, changing r in Eq. (7) to 0 or 1, as well as changing the period of function, that is, a in Eq. (7) makes it possible to increase the number of encoding codes twice as large as in the case of changing only the period (a) for encoding.

[Modification of Embodiment 1-2]

Although in Embodiment 1-2 the optical code signal is output only when the data in the data sequence is "1" (mark), the optical code signal may also be output when the data is "0" (space). That is, the n-th optical code signal Cn(f) is output for the data "1" (mark) in the n-th data sequence and an complementary optical code signal Cn'(f) of the n-th optical code signal Cn(f) is output for the data "0" (space). To perform this, the encoder 11_n is provided with a switch 45 which is disposed subsequent to the output-side coupler 44 as indicated by the broken lines in Fig. 7; the switch 45 is supplied with the outputs A and B and is controlled by the value of each piece of data of the data sequence Dn to provide the output A for the data "1" (mark) and the output B for the data "0" (space), generating a non-return-to-zero optical modulation signal.

[0033] In this embodiment, Eqs. (9) and (10) hold for the mark.

$$\int Cn(f)\, Dn(f) = FSR/4 \qquad (9)$$

$$\int Cn(f)\, Dm(f) = 0 \qquad (10)$$

For the space, Equations (11) and (12) holds. In this example, too, FCL = FSR.

$$\int Cn'(f)\, Dn(f) = -\, FSR/4 \qquad (11)$$

$$\int Cn'(f)\, Dm(f) = 0 \qquad (12)$$

In this embodiment, too, integration is conducted over the optical frequency width FSR of the light source, and the width FSR is equal to the code length FCL.

[0034] Accordingly, the optical intensity difference detector 57 outputs a signal composed of mark and space codes and hence twice (3 dB) larger than in the above-described embodiment in which the intensity difference detector 57 is supplied with only the "mark" optical signal and provides an output that goes to FSR/4 for the mark and to 0 for the space. This increases the signal-to-noise ratio by 3 dB and hence permits reduction of FSR accordingly, thereby lessening the influence of wavelength dispersion of the transmission line. Incidentally, the switch 45 may also be disposed at the stage preceding the input-side coupler 43, as indicated by the broken line in Fig. 7, in which case the input light is input to either one of two input ports of the coupler 42, depending on the data Dn is mark or space, and the output light is derived from only one of the output ports of the output-side coupler 41. Also the signs of the mark ("1") and the space ("0") may be exchanged. In other words, the correspondence between the mark ("1") and the space ("0") and between the optical code signals Cn(f) and Cn'(f) may be arbitrary.

[0035] The encoder 11_n may also be configured as depicted in Fig. 9. As is the case with an LN modulator, there are formed on a planar lightwave circuit substrate 46 formed of a material which has an electrooptic effect, such as

$LiNbO_3$ crystal: two waveguides 47 and 48; couplers 43 and 44 formed by

bringing the waveguides close to each other at locations adjacent their opposite end portions; and a pair of electrodes 49 for applying an electric field to at least either one of two optical paths 41 and 42 formed by the waveguides between the couplers 43 and 44 so as to provide a propagation delay difference between the two optical paths 42 and 41 by birefringence shift that is caused under the electric field by the electrooptic effect. The voltage that is applied to the optical path (waveguide) by the pair of electrodes 49 is adjusted such that the encoder 11_n selects and outputs the optical frequency (wavelength) signal which satisfies Eq. (7) corresponding to each optical code signal Cn(f).

[0036] The decoder 12_n can similarly be formed as a Mach-Zehnder interferometer or filter by forming optical paths 51, 52 and the couplers 53, 54 on the planar lightwave circuit substrate as parenthesized in Fig. 9. In this instance, the voltage to be applied to the electrodes 49 is so adjusted as to satisfy Eq. (8).

With the Fig. 9 configuration, it is possible to change the encoding code Cn(f) or decoding code Dn(f) by changing the voltage which is applied to the electrodes 49--this eliminates the need for forming a different encoder-decoder pair for each encoding code, and hence permits reduction of the device manufacturing costs.

Further, as depicted in Fig. 9, a pair of encoders 11_n and 11_m ($n \neq m$) are integrated on the same planar lightwave circuit substrate 46 whose temperature varies uniformly throughout it, and these encoders 11_n and 11_m generate n- and m-th optical code signals Cn(f) and Cm(f) which are common in the value a but different in the value r in Eq. (7), respectively. Since the two optical code signals Cn(f) and Cm(f) are identical in their optical frequency characteristic and are phased $\pi/2$ apart, unsimultaneous

occurrence of temperature variations in the encoders 11_n and 11_m for encoding the optical code signals, respectively, changes their refractive indexes and optical path lengths and hence causes their optical frequency for filtering to drift, resulting in deterioration of the the value of cross-correlation between the optical code signals Cn(f) and Cm(f). With the Fig. 9 configuration, however, it is possible to suppress the deterioration of the correlation between the optical code signals by temperature variations since the encoders 11_n and 11_m are mounted on the common planar lightwave circuit substrate which undergoes uniform temperature variations.

[Embodiment 1-3]

In Embodiment 1-3 of the first mode of working of the invention, the intensity of the chip, which is each optical frequency component of the optical code signal, goes to a 1 or 0. The configuration of the communications system to which Embodiment 1-3 is applicable may be the same as the Fig. 4 configuration.

[0037] The optical code signals, i.e. first to N-th optical code signals, generated by the encoder 11_n in Embodiment 1-3 have the same code length FCL and are orthogonal to each other as in Embodiments 1-1 and 1-2; and they have such properties as mentioned below. The numbers of chips "1" and chips "-1" in a string of chips of the code length FCL arbitrarily taken out of a continuously repeated concatenation of the encoding code Cn(f) of the code length FCL are equal (the same number), and the numbers of chips which simultaneously go to "1s" and "-1s", respectively, at the same positions in strings of chips of the code length FCL arbitrarily taken out of different concatenations of different encoding codes are equal to each other. In the case of a code composed of such chips, the code length is a mere abstract number with no unit. The product of the code length, that is, the number of

chips forming the code, and the optical frequency width of a chip corresponds to the optical frequency width FCL. Accordingly, it can be said in the above-described

embodiments, too, that the code length is the optical frequency width FCL over which all codes repeat.

[0038] Such a code can be generated by use of the Hadamard code. Fig. 10(a) shows a first-order Hadamard matrix H_1, Fig. 10(b) a second-order Hadamard matrix H_2, and Fig. 10(c) a recurrence formula H_n of the Hadamard matrix. A Hadamard code word is a selected row from the Hadamard matrix, except the first row, and its 0 and 1 are substituted with 1 and -1, respectively. In the second-order Hadamard matrix, the Hadamard code is composed of a code 2 [0101] in the second row of the matrix, a code 3 [0011] in the third row, and a code 4 [0110] in the fourth row. Continuously repeated concatenations of these codes 2 to 4 are [...0101010101...], [...001100110011...], and [...011001100110...], respectively. In this case, since the concatenation of code 3 and the concatenation of code 4 have their 1-chip codes shifted from each other, they constitute identical encoding codes, and Embodiment 1-3 uses only one of them.

[0039] In the encoder 11_n, consecutive optical frequencies are sequentially assigned to respective chips of such a concatenated code in the order of their arrangement, and those optical frequency components of the input light corresponding to the chips "1" are selected, that is, encoded. The selection optical frequency components of the encoder corresponding to the concatenation of the code C_1 = (0101) are such as depicted in Fig. 11(a), and the selection optical frequency components of the encoder corresponding to the concatenation of the code C_2 = (0011) are such as depicted in Fig. 11(b).

The encoder 11_n is configured to receive from the light source a light input of an optical frequency width F_w (= FSR) equal to a natural-number multiple of the code length FCL and hence filter the optical frequency signal (component) corresponding to each chip of the

concatenation of the encoding coder Cn(f) and output the filtered optical frequency signals as the optical code signal Cn(f) corresponding to the N-th data sequence, or output the optical code signal Cn(f) of the N-th data sequence in which the optical frequency signal (component) corresponding to each chip is ON for the data "1" of the N-th data sequence and OFF for the data "0". The thus encoded optical code signals each possess the above-mentioned properties of the chip string arbitrarily taken out from the concatenation of codes, maintaining orthogonality between different optical code signals.

[0040] The decoder 12_n also filters the optical frequency component (signal) of the input light corresponding to the concatenated code as is the case with the encoder 11_n, and performs decoding over the frequency width corresponding to at least the decoding optical frequency region from Fst to Fla. Fig. 12 shows an example of the configuration of the decoder 12_n. The multiplexed optical code signal is split by a splitter 61 into two for application to filters 62a and 62b; the filter 62a filters the optical frequency signals of the same order of output from the corresponding encoder 11_n, that is, the optical frequency signals corresponding to the same chips as in the output from the corresponding encoder, and the filter 62b filters the optical frequency signals corresponding to complementary versions of the encoded codes of the corresponding encoders 11_n, that is, the optical frequency signals corresponding to chips not selected by the encoder 11_n. The optical intensity of the optical frequency signal filtered or selected by the filter 62a and the optical intensity of the optical frequency signal filtered or selected by the filter 62b are detected by detectors 63a and 63b, respectively, and the output from the detector 63b is subtracted by an intensity difference detector 64 from the output from the detector 63a. In this way, optical code signals

corresponding to consecutive

chips forming at least the encoded code are decoded from the output light of the encoder 11_n.

[0041] Referring next to Fig. 13, a description will be given of how Embodiment 1-3 excludes the influence of the source frequency drift. Fig. 13(a) shows the state in which there is no source frequency drift . The optical signal 20 of the source frequency width F_W corresponding to the code length FCL is output from the light source, and those optical frequency components of the optical frequency signal 20 corresponding to the chips "1" are filtered (encoded) by the encoder 11_n in its encoding optical frequency region 31, by which an optical code signal 21 is generated. The decoder 12_n filters the input optical code signal 21 in its decoding optical frequency region 32 to provide a decoded optical signal 22.

[0042] When the source frequency drifts by ΔF_1 as shown in Fig. 13(b), the optical signal 20 input to the encoder 11_n is shifted by ΔF_1 in the same direction as that of the source frequency drift in the encoding frequency region 31, in which the input optical signal is encoded into the optical code signal 21, whereas in the decoder 12_n the input multiplexed optical signal 21 is also shifted by ΔF_1 in the same direction as that of the source frequency drift in the decoding frequency region, in which the input signal is decoded into an output optical signal 22.

Similarly, even when the source frequency drift is ΔF_2 larger than in the above as shown in Fig. 13(c), if the drifted optical signal 20 remains within the encoding frequency region 31 and within the decoding frequency region 32, the optical signal is shifted by ΔF_2 in both regions and encoded and decoded, respectively; in either case, the optical code signal 21 held orthogonal to a different optical code signal as described previously.

[0043] Incidentally, since it is absolutely impossible for the optical signal to

When the optical frequency for encoding by the encoder drifts ΔF_1 as depicted in Fig. 20(b), the optical input is encoded by filtering into an optical code signal 21'. When the optical frequency for encoding undergoes a relatively large drift ΔF_1 as shown in Fig.20(c), the optical input is encoded by filtering into an optical code signal 21".

[0051] Either of the optical code signals 21' and 21" has the code length FCL; accordingly, the optical code signals 21' and 21" have the same properties as does the string of consecutive chips extracted from the concatenated code over the source frequency FSR (denoted by F_W in Fig. 20) as described previously. Therefore, the decoder 12_n selects respective optical frequency components of the optical code signals 21' and 22", and outputs decoded signals 22' and 22" as shown in Figs. 20(b) and (c), respectively; thus, this embodiment ensures satisfactory decoding. When the optical frequency for decoding drifts, the decoder 12_n described above with reference to Fig. 15 is used to shift the optical frequency for decoding, by which satisfactory decoding can be achieved.

[0052] As described above, according to Embodiment 1-3, even if one or both of the source frequency, the optical frequency region for encoding 31 and the optical frequency region for decoding 32 drift, as long as the optical frequency width of the optical signal fed from the light source lies within the regions 31 and 32 (the region 32 including the shift-controlled region), no degradation is caused in the optical intensity of the input to the decoder and the orthogonality to other optical code signals is also retained--this enables the decoder to perform satisfactory decoding.

[Modifications of Encoder and Decoder of Embodiment 1-3]

Fig. 21 illustrates another example of the filter for use in the encoder 11_n and decoder 12_n of Embodiment 1-3. The optical input is fed to a filter

84; the filter 84 outputs optical frequency signals of respective chips forming the encoding code to different ports, and outputs to the same port those optical frequency signals which are spaced apart the optical frequency corresponding to the code length. For example, assuming that the encoded code is composed of four chips and that optical frequencies F_1, F_2, F_3 and F_4 are sequentially assigned to the chips in the order of arrangement, an optical signal of an optical frequency $F_1 + qFCL$ (where $q = 0, 1, 2, \ldots$) is output to a port 1, and optical signals of optical frequencies $F_2 + qFCL$, $F_3 + qFCL$ and $F_4 + qFCL$ are output to ports 2, 3 and 4, respectively. As the filter that repeatedly outputs optical signals of consecutive frequencies to different ports as mentioned above, an AWG (Arrayed Waveguide Grating) can be used which is of the type that the product of the number of optical signals to be split and their frequency interval and the free space range of the optical signals to be output to the same port are equal to the code length FCL. Incidentally, while the Free Space Range defined for AWG is abbreviated as FSR, it is not the optical frequency width FSR used herein but, by the definition of FSR in this specification, it is represented as C/FCL (C: light speed).

[0053] The ports, at which the optical frequency signals corresponding to the selection frequency components, that is, chips "1" of the encoding code, of the filter 84 are provided, are connected via optical paths 85 to a coupler or combiner 86a, and the output from the coupler or combiner 86a is provided as the output A. The ports, at which the optical frequency signals corresponding to the chips "-1" of the encoding code, that is, unselected optical frequency signals, are provided, are connected via optical paths 87 to a coupler or combiner 86b, and the output from the coupler or combiner 86b is provided as the output B. The Fig. 21 example shows the path connection

for the encoding code $C_2 = (0011)$ depicted in Fig. 11(b). The ports 1 and 2 for F_1 + qFCL and F_2 + qFCL are connected via the optical paths 87 to the combiner 86b, whereas the ports 3 and 4 for F_3 + qFCL and F_4 + qFCL are connected via the optical paths 85 to the combiner 86a.

[0054] It will easily be understood that the filter of the Fig. 21 configuration can be used as a filter for either of the encoder 11_n and the decoder 12_n.

In the encoder 11_n either one of the couplers or combiners 86a and 86b and the optical paths 85 or 87 corresponding thereto can be omitted. Rather than the couplers or combiners 86a and 86b which split or couple light irrespective of its optical frequency and hence causes a splitting loss, it is preferable to use arrayed waveguide grating as combiners not as filters in the above example since the optical loss by the splitting loss can be reduced. This filter is smaller in the number of parts than the filter of Fig. 14, and hence has the advantage of low optical loss.

[0055] The encoder 11_n may be configured as shown in Fig. 22. The same filter as that 84 in Fig. 21 is used, and its ports are connected to a combiner 92 via switches $91_1, \ldots, 91_E$ (where E is the number of chips forming the encoding code) which selectively permit or inhibit the passage therethrough of light to optical paths $89_1, \ldots, 89_E$. Those of the switches $91_1, \ldots, 91_E$ which correspond to the chips "1" of the encoding code are turned ON and those corresponding to the chips "-1" are turned OFF.

Fig. 23 shows an example of the decoder formed using the filter 84. The decoder is provided with switches $93_1, \ldots, 93_E$ through which the optical paths $89_1, \ldots, 89_E$ connected to respective ports of the filter 84 are selectively connected to either one of combiners 92a and 92b, and those of the switches $93_1, \ldots, 93_E$ which corresponds to chips "1" are connected to the combiner 92a, whereas those corresponding to the chips "-1" are connected to the

combiner

non-temperature-adjusted side. As is the case with the Fig. 9 example wherein the two encoders 11_n and 11_m are formed on the same circuit substrate 46, the encoders, which encode optical code signals the cross-correlation between which degrades upon occurrence of individual temperature changes of the encoders, are integrated on the same planar lightwave circuit substrate which undergoes a uniform temperature change throughout it--this suppresses deterioration of the cross-correlation. The temperature of the planar lightwave circuit substrate may be controlled through utilization of the intensity of the light transmitted through the encoder. In the case of using two encoders each of which outputs an optical signal of an optical intensity-frequency characteristic function Cm(f) for the one value of binary data and an optical signal of an optical intensity-frequency characteristic function (1-Cm(f)) for the other value, the above-mentioned temperature adjustment may preferably be made in accordance with the intensity difference between the transmitted light outputs from the both encoders. Furthermore, in the case of using the Fig. 9 structure, the maximum number of system users decreases by half since each user is assigned two encoding codes. With the Fig. 28 structure, however, because of the combined use of the decoder and the encoder, the maximum number of system users does not decrease by half despite the use of the encoding scheme free from interference by reflected light. Though described above as using the same encoded code as that used in Embodiment 1-2, this embodiment can similarly be applied to the Hadamard optical code signals shifted one chip apart in Embodiment 1-3 since the one-chip shift can be suppressed.

[0061] Now consider such an optical communications system as shown in Fig. 29, which comprises: a plurality of local office devices; a plurality of optical fibers 13_A, 13_B and 13_C for transmitting therethrough signals from the local

optical frequency. In this instance, those of the chip light sources corresponding to the chips "1" forming the encoded code Cn(f) output optical signals but those chip light sources corresponding to the chips "0" do not output optical signals; that is, the chip light sources responds to the encoding code Cn(f) to provide the optical signals for the mark but not to provide the optical signals for the space.

[0063] The encoded code in Embodiment 1-3 has such characteristics as described below. When two arbitrary encoding codes are selected from among different encoding codes with the same code length FCL, they satisfy at least one of the following conditions:

Number of chip positions in chip strings of the first and second encoding codes where their corresponding chips simultaneously go to "1s" is equal to the numbers of chip positions where the first encoding code goes to a "1" and the second encoding code goes to a "-1"; or

Number of chip positions where the first and second encoding codes simultaneously go to "-1s" is equal to the numbers of chip positions where the first encoding code goes to a "-1" and the second encoding code goes to a "1"; and they also satisfy the following condition:

Numbers of chips "1" and chips "-1" in a continuous string of chips of the afore-mentioned code length FCL arbitrarily extracted from the concatenated code of a continuous repetition of the encoding codes are equal to each other irrespective of any particular strings of chips; and they also satisfy at least one of the following conditions:

Number of chip positions where first and second continuous strings of chips of the code length FCL, arbitrarily extracted from different concatenated codes of continuous repetitions of two different encoding codes, simultaneously go to "1s" and the chip positions where first chip string goes

to a "1" and the second ship string goes to a "-1" are equal to each other; or

Number of chip positions where the first and second chip strings simultaneously go to "-1s" and the number of chip positions where the first chip string goes to a "-1" and the second chip string goes to a "1" are equal to each other. And the chips forming the encoding code are sequentially assigned consecutive optical frequencies corresponding to the chip strings.

[0064] The source optical frequency width FSR is a natural-number multiple of the code length FCL of each encoding code Cn(f), and the optical frequency region 31 for encoding by each encoder 11_n and the optical frequency region 32 for decoding by each decoder 12_n are both within the optical frequency range from Fst to Fla, where Fst – Fla > FSR. And it is evident that Cn(f) = Cn(f + FCL) holds in FSR in the range from Fst to Fla and that Eq. (13) holds between the code Cn(f) and its complementary code (1 - Cn(f)) as follows:

$$\int Cn(f) \cdot Cn(f)df > \int Cn(f) \cdot (1 - Cn(f))df \qquad (14)$$

where $\int df$ represents a definite integral with respect to f in an arbitrary interval FSR in the optical frequency range from Fst to Fla.

[0065] It is also clear that Cn(f) bears the relationship of the following equation (15) to the encoding code Cm(f).

$$\int Cn(f) \cdot Cm(f)df = \int Cn(f) \cdot (1 - Cm(f))df \qquad (15)$$

In Embodiment 1-2, as is evident from Eq. (7), it is possible to use, for each Cn(f), an encoded code with r being 0 or 1, and a = n/2.

[Second Mode of Working] (Optical Phase·Amplitude Modulation)

The second mode of working of the present invention is intended as a solution to the problems of the prior art through phase modulation and phase or amplitude modulation of a carrier on the optical frequency axis.

[Embodiment 2-1]

Fig. 30 illustrates an optical communications system according to Embodiment 2-1 of the second mode of working of the invention. In an optical transmitter 100 a transmission signal from an input terminal 101, usually a binary data sequence signal, is converted by a signal-phase converter 110 into a phase shift (phase shift value) sequence or modulation phase sequence (hereinafter referred to also as a modulation unit sequence), where the value of phase shift corresponding to every V pieces of data (where V is an integer equal to or greater than 1) is less than one period. An optical signal from a light source 120 is fed to a phase modulation part 130, wherein the phase of a pseudo-carrier on the optical frequency (wavelength) axis starting at a predetermined optical frequency (wavelength) as a reference is shifted to each phase amount fed from the signal-phase converter 110. The pseudo-carrier will sometimes be referred to simply as a carrier.

[0066] It is clear that, as described later, an optical signal as a phase-modulated pseudo-carrier is an "optical signal which is characterized by a certain optical filtering frequency characteristic function," an "optical signal coded by a certain code," or "an optical signal filtered by optical filtering frequency characteristic function." Since in the second mode of working of the invention the pseudo-carrier on the optical frequency axis is subjected to a modulation similar to QPSK or QAM modulation for the carrier on the time axis used in radio communications, the term "pseudo-carrier" will be used primarily in the interests of better understanding of the invention.

For example, as shown in Fig. 31, the data sequence is divided into data sets each consisting of V = 2 pieces of data, and the data sets are each assigned a different phase shift amount, that is, a phase amount shifted from a reference phase 0 (which will hereinafter refer to the phase shift amount). For example, data sets (0, 0), (0, 1), (1, 0) and (1, 1) are converted to phase

amounts 0, $\pi/2$, π, $3\pi/2$, respectively, which are less than one period.

[0067] Assume that an optical frequency difference from the reference optical frequency fs is a phase f, 400 GHz is one period Λ, and an optical signal that is coded by a function which is obtained, by adding 1 to and dividing by 2, a trigonometric function that means the optical intensity of each optical frequency signal, is the pseudo-carrier. When the phase f is 0, $\pi/2$, π, and $3\pi/2$, the optical frequency characteristics become as shown in Figs. 31(a) to 31(d), respectively; that is, for each $\pi/2$ shift of the phase f, the optical frequency shifts by 100 GHz. In Figs. 31(a) to 31(d) the leftmost diagrams each show the pseudo-carrier in terms of vector on a complex plane, the second from the left the instantaneous phase-intensity characteristic of the pseudo-carrier and the rightmost its optical intensity-frequency characteristic.

[0068] Letting an n-multiple of the period Λ of the pseudo-carrier be represented by FSR, that is, FSR = FCL = $n\Lambda$ (where n = 1, 2, ...), the light source 120 outputs an optical signal of at least the optical frequency width FSR. In this embodiment, too, it is assumed that the source frequency width FSR and the code length FCL are equal to each other. In this embodiment the code length will hereinafter be identified by FSR in place of FCL. The output optical signal from the phase modulation part 130 is $((1 + \cos(2\pi fn/FSR + \Theta)))/2$ whose phase shift amount is any one of $\Theta = 0, \pi/2, \pi$ and $3\pi/2$.

In an optical receiver 200 the received light is split by a splitter 210 for input to four filters 221, 222, 223 and 224 corresponding to the phase shift amounts 0, $\pi/2$, π and $3\pi/2$, respectively, the intensity of light transmitted through the filters 221, ..., 224 is detected by detectors 231, ..., 234. The outputs from the detectors 231, 233 and the outputs from the detectors 232, 234 having detected output light intensities of the filters corresponding to the phase shift amounts displaced one-half period apart, respectively, are

subtracted from each other by comparators 241 and 242, respectively. The outputs from the comparators 241 and 242 are converted by a code-signal converter 250 to a data set corresponding to the phase shift amount of the

$$= (1/8\pi) \int (1 + \cos 2(2\pi f/FSR + \Theta) + 2 \cos(2\pi f/FSR + \Theta))df = 0.25 \quad (17)$$

The first and second terms on the left side correspond, for example, to the output from the detector 231 and the output from the detector 233, respectively.

(2) In the case of the comparator output corresponding to the filters which have a filtering characteristic phase $\pi/2$ apart from the optical frequency characteristic of the phase modulator output light corresponding to the phase shift amount of the input to the phase modulation part 130:

$$(1/2\pi) \int ((1 + \cos(2\pi f/FSR + \Theta))/2) ((1 + \cos(2\pi f/FSR + \Theta + \pi/2))/2)df -$$
$$(1/2\pi) \int ((1 + \cos(2\pi f/FSR + \Theta))/2) ((1 + \cos(2\pi f/FSR + \Theta - \pi/2))/2)df$$
$$= (1/8\pi) \int (- 2 \sin(2\pi f/FSR + \Theta) + \sin 2(2\pi f/FSR + \Theta))df = 0 \quad (19)$$

In this embodiment the number M of the phase shift amounts (phase shift values) possible for the pseudo-carrier is an even number 4, and since these phase shift amounts (phase shift values) are sequentially displaced $\pi/2$ apart, the receiving side uses filters of the same number as M, but in the case where the phase shift amounts (values) that the pseudo-carrier is allowed to take are not displaced π apart, the receiving side uses filters of the same characteristics as those of the output light of the phase shift amounts (values) that the pseudo-carrier is allowed to take and filters of characteristics phased the half period (π) apart from the output light of the phase shift amounts (values) that the pseudo-carrier is allowed to take. Accordingly, the optical receiver 200 requires 2M filters and comparators of the same number as M. In this instance, the value M is arbitrary, but the phase shift amounts (phase shift values) of the carrier by the phase modulation part 130 needs to be phase

serial-parallel converter 110a are converted by a D/A converter 110b to digital values 0, 1, 2 and 3 corresponding to combinations of the input data (0, 0), (0, 1), (1, 0) and (1, 1), respectively, and voltages corresponding to these values are applied to the electrode 49 in Fig. 9. In accordance with the applied voltage values the phase of the pseudo-carrier of the output light from the phase modulation part 130 varies as shown in Figs. 31(a) to 31(d).

[0076] The filter 131 in the optical transmitter 100 filters light from the light source 120 at least over the optical frequency width FSR, and the filtering characteristic, that is, the transmittance (optical intensity)-optical frequency characteristic is such that when the optical frequency difference from the reference optical frequency fs is used as phase, the transmittance (optical intensity) in each phase conforms to a function obtained, by adding 1 to and dividing by 2, a trigonometric function indicating the period obtained by dividing FSR by a natural number n.

A code signal converter 250 in the optical receiver 200 is configured, for example, as depicted in Fig. 30, in which outputs 0 or 1 from the comparators 241 and 242 are input in parallel to a parallel-serial converter 251, from which they are output as a single sequence of data signals to an output terminal 201. Thus, the transmission signal input to the input terminal 101 of the optical transmitter 100 is regenerated and output to the output terminal 201.

[0077] As described above, according to Embodiment 2-1, in order to emulate positive- or negative-polarized uncorrelated carriers by non-polarized intensity modulation which is a part of a repetition of a desired frequency period on the optical frequency axis, use is made of broadband light of an optical frequency width which is a natural-number of multiple of the pseudo-carrier period and a differential detection is conducted on the

embodiment be identified as an i-th carrier and setting $2\pi f = \Theta$, characteristic functions of the respective sets are $Ci(\Theta)$ or $Ci(\Theta + \pi)$ and $Ci(\Theta + \pi/2)$ or $Ci(\Theta + 3\pi/2)$, and assuming that $\int d\Theta$ is a definite integral over the interval FSR, the following equations hold.

[0079] $$\int Ci(\Theta)(Ci(\Theta + \pi/2) - Ci'(\Theta + \pi/2))d\Theta = \int Ci(\Theta)(Ci(\Theta + 3\pi/2) - Ci'(\Theta + \pi/2))d\Theta = 0 \qquad (20)$$

$$\int Ci(\Theta)(Ci(\Theta) - Ci'(\Theta))d\Theta = \int Ci(\Theta + \pi)(Ci(\Theta + \pi) - Ci'(\Theta + \pi))d\Theta \qquad (21)$$

Fig. 36(a) shows QPSK signal points (coordinate points) on a complex coordinates, and Fig. 36(b) shows, by way of example, signal data sets, coordinate points and sets of select filtering phases in the case of emulating QPSK. In this instance, the number of sets $M/2 = 2$, the phase shifts of the one data set are 0 and π, and the phase shifts of the other data set are $\pi 2$ and $3\pi/2$, and their coordinate points are shown on a unit circle in Fig. 36(a). 0 and π in the data set of phase shifts 0 and π correspond to 1 and -1 on the x-axis, respectively, whereas $\pi/2$ and $3\pi/2$ in the data set of phase shifts $\pi/2$ and $3\pi/2$ correspond to 1 and -1 on the y-axis, respectively. The coordinate points are indicated in the parentheses with the x-axis values at the left-hand side and the y-axis values at the right-hand side.

[0080] The phase modulation part 130 outputs light of the pseudo-carrier of the 0-phase shift or π-phase shift corresponding to one bit of the two-bit data set, in the example of Fig. 36(b), the high-order bit (data) a 0 or 1 and outputs light of the pseudo-carrier of the $\pi/2$-phase shift or $3\pi/2$-phase shift corresponding to the low-order bit (data) a 0 or 1. That is, it can be said that the output from the phase modulation part is an optical code signal indicating the combination codes of the two pieces of data in the data sequence for each modulation unit of the pseudo-carrier light output from the phase modulation

which light is input. For example, as shown in Fig. 35(b), the light emitted from the light source 120 is split by a splitter 134' into two, the one of which is selectively fed into the 0-phase filter 133a or π-phase filter 133c via a switch serving as a modulator 132a', and the other of which is selectively fed into to the $\pi/2$-phase filter 132b or $3\pi/2$-phase filter 132d via a switch serving as a modulator 132b', and the optical outputs from the filters 133a to 133d are provided via the combiner 136 to the optical transmission line 300. On both of the input and output sides of the filters 133a to 133c modulators may be disposed as switches, permitting the passage of light from the light source through only a selected one of the modulators.

[0082] The optical receiver corresponding to this embodiment may be of the same configuration as shown in Fig. 30. In such an instance, however, since the comparators 241 and 242 output +1s or −1s, converting parts 241a and 242a are used in the optical transmitter 200, as indicated by the broken lines in Fig. 30, to convert −1s to 0s, which are provided to the code converter 250. It will be easily be understood that the code converter 250 thus provides the same signal sequence as the input transmission signal sequence to the optical transmitter 100.

In this way, QPSK can be implemented with a lower degree of control accuracy on the order of optical wavelength.

[Embodiment 2-4]

Embodiment 2-4 emulates 16-QAM by use of pseudo-carriers. In this embodiment, two sets of pseudo-carriers, each consisting of two pseudo-carriers displaced half a period (π) apart in phase, are used to emulate light from the light source according to 16 kinds of data sets in this example, the pseudo-carriers of the one and the other set are phased a quarter period ($\pi/2$) apart and orthogonal to each other, and optical signals with these four

piece of data of the second separate data sequence.

The modulators 151 and 152 may also be inserted between the light source 120 and the filters 133a to 133d as depicted in Fig. 39. In this instance, the light from the light source 120 is split by the splitter 134 into two, one of which is input first to the modulator 151, wherein its intensity is controlled by the amplitude changing part 151b to go to a 3 or 1 according to the third high-order data, and the thus intensity-controlled light is output via the switch 151a to the 0-phase filter 133a or π-phase filter 133c according to the highest-order data. The other split light from the splitter 134 is input first to the modulator 152, wherein its intensity is controlled by the amplitude changing part 152b to go to a 3 or 1 according to the lowest-order data, and the thus intensity-controlled light is output via the switch 152a to π/2-phase filter 133b or 3π/2-phase filter according to the second high-order data.

[0086] It is also possible to intensity-control the optical inputs to the two sets of filters by the amplitude changing parts 151b and 152b according to the third high-order data and the lowest-order data, respectively, and select the filters of the two sets of filters by the switches 151a and 152a according to the highest-order data and the second high-order data, respectively. Alternatively, it is possible to input the light from the light source to either one of the two filters of each set and intensity-control the optical outputs from the filters of the two sets by the amplitude changing parts 151b and 152b, respectively.

The optical receiver 200 uses, as shown in Fig. 37-2, the same filters 221-224, detectors 231 to 234 and comparators 241, 242 as those shown in Fig. 30, but uses, as a substitute for the code signal converter 250, a code signal converter (data generating means) 260 of the type that converts the outputs from the comparators 241 and 242 to a set of four pieces of data

corresponding to two levels (intensities) including polarities (positive and negative), that is, four levels, and outputs these pieces of data in serial form. In other words, the comparators 241 and 242 each outputs any one of 3, 1, −1 and −3 shown in Fig. 38(b); and a data set shown in Fig. 38(b) is provided corresponding to such a combination of the outputs.

[0087] In such a code signal converter 260, for instance, as depicted in the optical transmitter of Fig. 37-2, the outputs from the comparators 241 and 242 are converted by A/D converters 262 and 262 to 3-bit digital values each containing a sign (code); these 3-bit (a total of 6 bits) digital values are used as addresses to read a conversion memory 265 to obtain therefrom a data set of such four corresponding bits as depicted in Fig. 38(b), and the output data set is converted by a parallel-serial converter (data generating means) 266 to serial data, which is provided to an output terminal 201. Incidentally, let it be assumed that the relationships between the addresses thereto and the data to be read out thereof are prestored in the conversion memory 265 in such a manner as to obtain the relationships between the comparator outputs and the data sets shown in Fig. 38(b).

[0088] As described above, according to Embodiment 2-4, as is the case with Embodiment 2-1, in order to emulate positive- or negative-polarized uncorrelated carriers by non-polarized intensity modulation which is a part of a repetition of a desired frequency period on the optical frequency axis, use is made of broadband light of an optical frequency width which is a natural-number multiple of the pseudo-carrier period and a differential detection is conducted on the receiving side to inhibit the input thereto of pseudo-carriers other than those to be received; thus, even if light of the same optical frequency is used, the correlation between pseudo-carriers is eliminated which is attributable to trigonometric functions that are not

[0090] $\pi/2$-phase filter 137b: Filter by repeatedly turning OFF (interrupt) consecutive S chips, then ON (pass) the next 2S chips, and OFF (interrupt) the next S chip until L is reached.

π-phase filter 137c: Filter by repeatedly turning OFF (interrupt) consecutive 2S chips and ON (pass) the next 2S chips until L is reached.

$3\pi/2$-phase filter 137d: Filter by repeatedly turning ON (pass) consecutive 2S chips, then OFF (interrupt) the next 2S chips, and OFF (interrupt) the next S chip until L is reached.

[0091] In Fig. 41 there are shown filtering frequency characteristics of the filers 137a, 137b, 137c and 137d, for example, in the case where L = 4 and S = 1. In Figs. 41(a), 41(b), 41(c) and 41(d) where FSR/n corresponding to 4S chips is one period on the optical frequency axis and one-half the period corresponds to 2S chip, i.e., one period is 2 π, there are shown filtering characteristics of the filters 137a, 137b, 137c and 137d which permits the passage therethrough of light of 2S chips of π-width shifted to 0-, $\pi/2$-, π- and $3\pi/2$-phase positions, respectively. Accordingly, the light having passed through these filters 137a, 137b, 137c and 137d becomes such that a pseudo-carrier of the period FSR/n on the optical frequency (wavelength) axis, which is a rectangular pattern of the π-width, that is, of a 50% duty ratio, is phase-modulated to 0, $\pi/2,\pi$ and $3\pi/2$, respectively. Here, FCL = FSR.

[0092] Embodiment 2-5 enables implementation of the QPSK modulation by associating two pseudo-carriers of such phases and two data sets. In Embodiment 2-5, since the filters 137a, ..., 137d are associated with 0, ..., $3\pi/2$, respectively, the two pieces of data from the signal-to-phase converter 110 are used, as is the case with the optical transmitter of Fig. 35(a), to control the modulators 132a and 132b to select the output light from the 0-phase filter 127a or the output light from the π-phase filter 137c and the

show modulation part outputs corresponding to the phase shifts 0, $\pi/2$, π, $3\pi/2$, respectively. In the columns third from the left-hand side, the filtering characteristics (functions) of the filters 225 to 228 in the optical receiver 200 are shown in first to fourth rows of the columns, respectively. In each of Figs. 42-1 to 42-4 the column fourth from the left-hand side shows in its first to fourth rows the optical frequency characteristics of light passing through the filters 225 to 228 in the case where the modulation part outputs shown there are input to the filters, respectively. The rightmost columns show in their first to fourth rows temporal changes of the intensities to be detected by the detectors 231 to 234, respectively.

[0095] As shown in Figs. 42-1 to 42-4, assuming that the power at the detector at the time of all the chips passing through the filters is 1, the detected intensity corresponding to the filter of the same filtering characteristic as the optical frequency characteristic of the modulation part output is 0.5, and the detected intensity corresponding to the filter of a filtering characteristic displaced π apart from the optical frequency characteristic of the modulation part output is 0; the comparator that compares these detector intensities provides an output of 0.5. For example, in Fig. 42-1, when the modulation part output in the first row is input, the detected intensity of the output light from the filter 231 is 0.5 as shown in the first row, and the detected intensity of the output from the filter 233 is 0 as shown in the third row. Since the detected intensities corresponding to the filters whose filtering characteristics are displaced $\pi/2$ and $3\pi/2$ apart from the optical frequency characteristic of the modulation part output are both 0.25, the comparator that compares the both detected intensities provides an output 0. For example, in Fig. 42-1, the detected intensities of the optical outputs from the filters 232 and 234 are both 0.25 as shown in the second and fourth rows,

respectively.

[0096] It is desirable that the transmission characteristic of each chip on the optical frequency axis be rectangular, but it is shown in a triangular form for easy distinction of individual chips. In this case, however, since the power at the detector at the time of all the chips passing through the filters is normalized to 1, Embodiment 2-5 operates as described previously without losing generality, irrespective of whether the transmission characteristic is triangular or Gaussian distribution on the optical frequency axis.

In Fig. 40 there is shown only a single combination of the optical transmitter 100 and the optical receiver 200, but when other optical transmitter and optical receiver share the same optical transmission line 330 at the same optical frequency, a different value of L is chosen. L is a multiple of 4 corresponding to the phase shift number M and is a value obtained by dividing the chip number of the optical frequency width FSR by an arbitrary integer n. The value S is a value obtained by dividing L by the phase shift number M, that is, by 4. Letting the number of the phase shift amount be represented by P, P = 0, 1, 2, 3, and P = 0, P = 1, P = 2 and P = 3 correspond to the phase shifts, 0, $\pi/2$, π, and $3\pi/2$, respectively. That is, $2\pi P/M$ ($M = 4$). Every L chips it is repeated at least n times to provide the transmittance 1 for chips corresponding to the remainders concerning the value L obtained by adding 1 to L/2 to PS which is obtained by multiplying the number P of the phase shift amount by S and the transmittance 0 for the other chips. That is, letting MOD(A, L) represent the remainder of the division of A by L, the transmittance 1 is provided for chips of the chip numbers corresponding to Q changing from 1 through the above-mentioned n in $(Q - 1)L + \mathrm{MOD}(PS + 1, L)$ to $(Q - 1)L + \mathrm{MOD}(PS + L/2, L)$, and the transmittance 0 is provided for the other remaining chips. Since the product of the value L chosen here and

embodiment is an i-th carrier and that $2\pi f = \Theta$, the filtering characteristic functions of each set are $Ci(\Theta)$ or $Ci(\Theta + \pi)$ and $Ci(\Theta + \pi/2)$ or $Ci(\Theta + 3\pi/2)$; letting Σ represent the sum of addition from $h = 0$ to $FSR/\ \delta\Theta - 1$ over the period FSR where $\Theta = h\delta\Theta$, the following equations hold:

[0099] $\Sigma Ci(\Theta)(Ci(\Theta + \pi/2) - Ci'(\Theta + \pi/2)) = \Sigma Ci(\Theta)(Ci(\Theta + 3\pi/2) - Ci'(\Theta + 3\pi/2)) = 0$ (22)

$$\Sigma Ci(\Theta)(Ci(\Theta) - Ci'(\Theta)) = \Sigma Ci(\Theta + \pi)(Ci(\Theta + \pi) - Ci'(\Theta + \pi)) \quad (23)$$

Eqs. (22) and (23) are formulae for digital processing of integrations of Eqs. (20) and (21), respectively.

It will easily be understood that the QAM modulation can be emulated using the pseudo-carriers shown in Embodiment 2-4 and by the same method as described previously with reference to Figs. 37-1 and 37-2. For this QAM modulation, as parenthesized in Figs. 37-1 and 37-2, the optical transmitter 100 uses filters 137a to 137d as substitutes for the filters 133a to 133d, in which case according to two bits of the data set from the signal-to-phase and amplitude converter 111 the modulator 151 selects one of the filters 137a and 137c to control the optical intensity to be either 1 or 3, whereas according to the other two bits in the data set the modulator 152 selects one of the filters 137b and 137d to control the optical intensity to be either 1 or 3. In this instance, the optical receiver 200 needs only to use filters 225 to 228 as substitutes for the filters 221 to 224, and no further modifications are needed. The positions where to dispose modulators 151 and 152 are the same as in the case of Embodiment 2-4. Embodiment 2-6 also produces the same effects as are obtainable with Embodiment 2-6 for the same reasons as in the latter.

[0100] Further, the MPSK modulation can be emulated by using the

8) and (2, 12, 3, 4). The gray color means chips of the transmittance 1. In the case of (n, L, M, S) = (1, 24, 3, 8), since n = 1, there is only Q = 1: for a phase shift 0 (P = 0), the first ((1 − 1)24 + Mod(0 · 8 + 1, 24) = 1) chip a to the 12th ((1 − 1)24 + Mod(0 · 8 + 24/2, 24) = 12) chip b have the transmittance 1 as shown in the left-hand diagram of Fig. 44(a); for a phase shift 2π·(1/3) (P = 1), the ninth ((1 − 1)24 + Mod(1 · 8 + 1, 24) = 9) chip a to 20th ((1 − 1)24 + Mod(1 · 8 + 24/2, 24) = 20) chip b have the transmittance 1 as shown in the left-hand diagram of Fig. 44(b); and, for a phase shift 2π·(2/3) (P = 2), the 17th ((1 − 1)24 + Mod(2 · 8+1, 24) = 17) chip a to the fourth ((1 − 1)24 + Mod(2 · 8 + 24/2, 24) = 4) chip b have the transmittance 1 as shown in the left-hand diagram of Fig. 44(c). That is, since the maximum chip number is 24, the first to fourth chips and the 17th to 24th chips go to 1s.

[0102] In the case of (n, L, M, S) = (2, 12, 3, 4), since n = 2, there are Q = 1 and Q = 2. As shown in the right-hand diagrams of Figs. 44(a) to 44(d): in the case of the phase shift P = 0, for Q = 1, the first ((1 − 1)12 + Mod(0 · 4 + 1, 12) = 1) chip a to the sixth ((1 − 1)12 + Mod(0 · 4 + 12/2, 12) = 6) chip b are made 1's, and for Q = 2,the 13th ((2 − 1)12 + Mod(0 · 4 + 1, 12) = 13) chip c to the 18th ((2 − 1)12 + Mod(0 · 4 + 12/2, 12) = 18) chip d are made 1's ; in the case of the phase shift 2π·(1/3) (P = 1), for Q = 1, the fifth ((1 − 1)12 + Mod(1 · 4 + 1, 12) = 5) chip a to the 10th ((1 − 1)12 + Mod(1 · 4 + 12/2, 12) = 10) chip b are made 1's, and for Q = 2, the 17th ((2 − 1)12 + Mod(1 · 4 + 1, 12) = 17) chip c to the 22nd ((2 − 1)12 + Mod(1 · 4 + 12/2, 12) = 22) chip d are made 1's; and in the case of the phase shift 2π·(2/3) (P = 2), for Q = 1, the first to second chips and the ninth to 12th chips are made 1's, and for Q = 2, the 13th to 14th chips are made 1's and the 21st to 24th chips are made 1's. That is, for Q = 1, the ninth ((1 − 1)12 + Mod(2 · 4 + 1, 12) = 9) chip a to the second ((1 − 1)12 + Mod(2 · 4 + 12/2, 12) = 2) chip b are made 1's, and for Q

= 2, the 21st ($(2 - 1)12 + \mathrm{Mod}(2 \cdot 4 + 1, 12) = 21$) chip c to the 14th ($(2 - 1)12 + \mathrm{Mod}(2 \cdot 4 + 12/2, 12) = 14$) chip d are made 1's. In this instance, for Q = 1, the range over which the chip 1 can be shifted is from the first to 12th chip position, whereas for Q = 2 it is the range from the 13th to 24th chip positions. In this embodiment, too, as will be evident from Fig. 44, even if other signals having different values of n are received, the interference between pseudo-carriers is cancelled at the receiving side, and hence they can be received independently of each other.

[0103] The filter of the optical transmitter according to this embodiment is provided with three 0-, $2\pi/3$- and $4\pi/3$-phase filters in place of the four 0-, π-, $\pi/2$- and $3\pi/2$-phase filters forming the filter 137 in Fig. 40 illustrating Embodiment 2-5. Instead of using the four 0-, π-, $\pi/2$- and $3\pi/2$-phase filters and two sets of comparators for comparing the outputs from detectors connected to the four filters whose phase shift amounts differ in steps of π, the optical transmitter of this embodiment is provided with the three 0-, $2\pi/3$- and $4\pi/3$-phase filters, three π-, $5\pi/3$- and $\pi/3$-phase filters, three π-, $5\pi/3$- and $\pi/3$-phase filters whose phase shift amounts differ by π from them, respectively, and three sets of comparators for comparing outputs from detectors connected to the filters whose phase shift amounts differ in steps of π.

[0104] As described above, positive- or negative-polarized uncorrelated carriers are emulated by non-polarized intensity modulation which is a part of a repetition of a desired frequency period of broadband light on the optical frequency axis, and the emulated carriers are phase-modulated; by this, it is possible to implement MPSK with control accuracy lower than that on the order of the wavelength of light.

[Embodiment 2-7]

The π-phase filter 133c (137c) and $3\pi/2$-phase filter 133d (137d) in

the optical transmitter 100 shown in Fig. 37-1 are omitted, the switches 151a and 152a in the modulators 151 and 152 are omitted accordingly, the 0-phase filter 133a (137a) and the π/2-phase filter 133b (137b) are connected to the amplitude changing parts 151b and 152b in the modulators 151 and 152, respectively, and the signal-to-phase and amplitude converter 140 is replaced with a signal-to-amplitude converter 112, that is, with the serial-parallel converter 110a in the signal-to-phase converter 110a shown in Fig. 30, by which the one bit (data) and the other bit (data) of a two-piece data set are made to correspond to the modulators 151 and 152 to effect control such that the optical intensity is a 3 or 1 depending on the bit 0 or 1. In the optical receiver 200, the code converter 260 provides data 0 or 1, depending on whether the output intensities of the comparators 241 and 242 are 3s or 1s, and outputs the pieces of data in serial form.

[0105] With such an arrangement, QAM modulation, which has four signal points in the first quadrant as depicted in Fig. 38(a), can be performed not only for the pseudo-carriers based on the trigonometric function on the optical frequency (wavelength) axis described previously with reference to Embodiment 2-4 but also for the rectangular pattern pseudo carriers on the optical frequency (wavelength) axis described above with reference to Embodiment 2-6.

Such QAM modulation with four signal points can be achieved as QAM modulation which has four signal points in any one of the second, third and fourth quadrants in Fig. 38(a), by use of two filters selected from among combinations of 133b (137b) and 133c (137c), 133c (137c) and 133d (137d) and 133a (137a) and 133d (137d). In these cases, when the outputs from the comparators 241 and 242 are negative, they are converted to data 0 or 1, depending on whether their absolute values are 3s or 1s.

emulate the π-phase carrier. The remaining L/2S sets of light sources are used to simulate the π/2-phase carrier or 3π/2-phase carrier. That is, the output light from a light source 120e which outputs the S chips succeeding the first S chips in each period on the optical frequency axis, that is, π/2-phase S chips, and the output light from a light source 120f which outputs the next S chips, that is, π-phase S chips, are used to emulate the π/2-phase carrier; and the output light from a light source 120g which outputs the next S chips, that is, 3π/2-phase S chips, and the output light from a light source 120h which outputs the next S chips, that is, 0-phase S chips, are used to emulate the 3π/2-phase carrier. These 0-phase, π/2- phase, π-phase and 3π/2-phase carriers correspond to the transmitted light of P = 0, P = 1, P = 2 and P = 3 in Fig. 43(a), respectively.

[0107] The above description has been given of the example in which n = 1, but when n is an integer equal to or greater than 2, the value of S corresponding to n in the order of optical frequency needs only to be allocated in S-chip blocks to the 0-phase light source, the π/2-phase light source, the π-phase light source and the 3π/2-phase light source. The value n that can be used is determined by the relation to the chip number L that corresponds to one period obtained by dividing the optical frequency width FSR by n. In the cases where FSR = 24, n = 2, L = 24/2 = 12 and S = 12/4 = 3, light of the 0-phase, π/2-phase, π-phase ad 3π/2-phase pseudo-carriers becomes the same as the transmitted light for P = 0, P = 1, P = 2 and P = 3 in Fig. 43(b). The value L is a multiple of 4 corresponding to the number M of phase shifts, and the value S is a value obtained by dividing the value L by the number M of phase shifts that is, by 4 (L = 4S). Every L chips it is repeated at least n times to turn ON (1) the light sources for chips corresponding to the remainders concerning the value L of the value obtained by adding 1 to L/2 to

switches 153d and 154d by each piece of data of the two-data set of the signal-to-amplitude modulator 112 in Fig. 37-1. Further, the QAM modulation described previously with reference to Embodiment 2-7 can also be achieved by: omitting the switches 153d and 154d are omitted; connecting the switches 153a and 154a to two sets of light sources (a total of four light sources) that output light of mutually orthogonal pseudo-carriers; and controlling the switches 153a and 154a as referred to previously in connection with Embodiment 2-7. Incidentally, in the example in which the switches 153a and 154a are omitted and in the example in which the switches 153d and 154d are omitted, the serial-parallel converter 110C is substituted with the serial-parallel converter 110a of the signal-to-phase converter 110 in Fig. 30.

[0111] The QAM modulation can also be implemented by use of two light sources whose phase shift amounts differ by $\pi/2$, for example, the 0-phase shift light source and the $\pi/2$-phase chip light source. In this instance, since the phase is one-half that in the QAM modulation by the embodiment described above with respect to Fig. 45, doubling the number of steps for intensity modulation control in the Fig. 45 embodiment enables signal transmission to be achieved at the same level as that by the embodiment. Additionally, the number of light sources used can be reduced by half.

It is also possible to perform, by use of multiple light sources, the same modulation as the MPSK modulation in which the number of phase shift positions is an arbitrary value M as described previously with respect to Embodiment 2-6. Referring to Fig. 45, this example will be described in connection with the case where M = 4. In this instance, the signal-to-phase and amplitude converter 113 in Fig. 45 is replaced with the signal-to-phase converter 110 in Fig. 30. And multiple light sources are used which provide, in each period FSR/n, 2S-chip optical outputs at the 0-, $\pi/2$-, π- and

271 and the detected optical intensity of the transmitted light through the i'-th filter 271', and, assuming the value Di(f) at the normalized optical frequency f, the output from the comparator 241 is given by Eq. (3) in the first mode of working of the invention.

$$Di(f) = Ci(f) - Ci'(f) \qquad (3)$$

By the detector 231 respective optical frequency components of the transmitted light through the i-th filter are detected as the optical intensity of the transmitted light as a whole. The same goes for the other detectors. Accordingly, the integration value of the scalar product of the filtering characteristic function Ci(f) of the i-th filter 161 of the transmitting side at the normalized optical frequency f and the filtering characteristic function Di(f) of the i-th filter 271 of the receiving side at the normalized optical frequency f over the continuous optical frequency range FSR in which to perform filtering by the i-th filter 271 is a non-zero finite value, and the relation of the following equation (5)' holds.

[0118] $$\int Ci(f)\, Di(f)\, df = P \qquad (5)'$$

Eq. (5)' corresponds to a generalized version of Eq. (5) shown in the first mode of working of the invention.

The integration value of the scalar product of the filtering characteristic function Ci(f) of the i-th filter in the phase f and the filtering characteristic function Dj(f) of an j-th filter other than the i-th one at the normalized optical frequency f over the continuous optical frequency range FSR contained in the optical frequency range which is filtered by the filter is zero, and Eq. (6) mentioned in the first mode of working of the invention holds.

$$\int Ci(f)\, Dj(f)\, df = 0 \qquad (6)$$

Accordingly, optical components having passed through the j-th filter

are not contained in the comparator output which is provided by subtracting the output of a detector 231' for detecting the intensity of transmitted light through the i'-th filter 271' from the output of the detector 231 for detecting the intensity of transmitted light through the i-th filter 271. Thus, Embodiment 2-9 enables the receiving side to cancel the input from the other pseudo-carriers except the target pseudo-carrier for receiving by differential detection.

[0119] Furthermore, the filtering characteristic function of the i-th filter 161 is a periodic function with the optical frequency as a variable, and it is preferable that the transmittance (value) Ci(f) at the normalized optical frequency f repeat in the period at intervals of PFRi (= FCL/n (= FSR/n = Λ)) so that Eq. (1) mentioned in the first mode of working of the invention holds.

$$Ci(f) = Ci(f + FCL) \qquad (1)$$

With such an arrangement, the receiving side is allowed to cancel, by differential detection, the input from the other pseudo-carriers except the target pseudo-carrier for receiving, not depending on the differences in optical frequency and in the reference optical frequency fs for each light source. In this way, Embodiment 2-9 implements QAM with control accuracy lower than that on the order of optical wavelength. It will be understood that Eqs. (1), (3) to (5)' hold for both of the pseudo-carriers based on the trigonometric function used in Embodiments 2-1 to 2-4 and 2-7 and the chip-structured pseudo-carriers used in Embodiments 2-5 to 2-8. Incidentally, in the case of the chip-structured pseudo-carriers, $\int d\Theta$ is replaced with Σ in the equations. Further, it will be seen that the integral over an interval from an arbitrary value f to f + FSR in the optical frequency region for filtering by the filter is a value obtained by dividing FSR by 2, allowing that Eq. (2) in the first mode of working of the invention also holds.

Hadamard code, for chips of the number derived from the division of the chip number corresponding to FSR/n, for instance, by the code length FCL of the Hadamard code. Moreover, in the case of using a filter which filters optical frequencies in the region equal to or wider than FSR in correspondence to a code that is a continuous concatenation of Hadamard codes, equations that have $\int d\Theta$ replaced with Σ in Eqs. (1) to (5) hold in an arbitrary optical frequency region FSR.

[0127] As described above, this embodiment also enables the receiving side to cancel the input from the other pseudo-carriers except the target

optical transmitters 100_1, …, 100_K correspond to a pair of fundamental and multiple periods generated by Fourier transform. For example, assuming that the value of the number N for dividing FSR is in the range of 1 to K, these FSR, FSR/2, …, FSR/K are used in the optical transmitters 100_1, 100_2, …, 100_K, respectively, and their optical signals are combined by the combiner 171 into a combined optical signal, which is equivalent to a signal subjected to inverse discrete Fourier transform processing.

[0133] Let the periods of filtering characteristic functions of the filters for use in the optical receiver 200 be represented by FSR, FSR/2, …, FSR/K, respectively. Such relationships provide an operation equivalent to that by which the received optical signal is split into optical signals and they are discrete-Fourier-transformed by the optical receivers 200_1, …, 200_K into the original transmission signal.

In this way, according to Embodiment 2-11, it is possible to implement pseudo OFDM (Orthogonal Frequency Division Multiplex) by use of multiple pseudo-carriers compatible with inverse discrete Fourier transform through utilization of the orthogonality between the pseudo-carriers. In the case where the optical transmitter 100 uses the optical transmitters 100_1, …, 100_K each of which is provided with filters of filtering characteristics phased $\pi/2$ apart for each period from the fundamental period to a period K/2 times the former, if the one of the $\pi/2$-phased-apart filtering characteristics in the optical transmitters 100_1, …, 100_K is a cosine function, the other is a sine function; the output from the optical transmitter 100 can be expressed by $\Sigma(an \cos((n/FSR)\ \Theta) + bn \sin((n/FSR)\ \Theta))$, where n is a value of a multiple of the filter period for the fundamental period, and an and bn are transmission signals that are carried by respective pseudo-carriers.

[0134] Even if the optical transmitter 100n and the optical receiver 200n are

not provided which correspond to an arbitrary period n including the

signal.

[0135] The filter for use in the optical transmitter of any embodiments described above may be a filter adapted to control its filtering characteristic by the modulator output as described previously in reference to Fig. 33; alternatively, the filter may be configured to select a plurality of filters of fixedly set filtering characteristics. Accordingly, to control the filter by the modulator means control of the filtering characteristic and control of selection of filters.

Since the signal-phase converter 110, the signal-to-phase and amplitude converter 111 and the signal-amplitude converter 112 are to convert, in accordance with signal data, the input thereto to parameters for controlling filtering characteristics, selective control of filters and intensity control of light from the optical transmitter, they can generically be called signal-to-modulation value converters, and the phase amount and amplitude amount output therefrom can be called modulated values, and their respective components can be referred to as parameters.

[0136] While the second mode of working of the invention, which performs MPSK or QAM by use of periodic functions on the optical frequency axis as mentioned above, has been described previously in in relation to its general configuration, but it can also be explained as follows. Letting the optical frequency width PFRi represent a value obtained by dividing the optical frequency width FSR, which is a natural-number multiple of the least common multiple, by an integer Ni corresponding to the repetition period of the i-th optical frequency characteristic function Ci(f) in the optical frequency width FSR in the optical frequency range from the optical frequency Fst to Fla,

$$Ci(f) = Ci(f + PFRi),$$

$$\int Ci(f) \cdot Cj(f)df > \int Ci(f) \cdot (1 - Ci(f))df,$$

and for the j-th optical frequency characteristic function Ci(f) other than the i-th one,

$$\int Ci(f) \cdot Cj(f)df = \int Ci(f) \cdot (1 - Cj(f))df;$$

and letting Δf represent the remainder of the division of the period PFRi of the function Ci(f) by an arbitrary optical frequency width equal to or narrower than FSR and a phase 2π (Δf/PFRi) represent the phase difference from Ci(f),

$$Ci'(f) = Ci(f + \Delta f),$$

that is, Ci'(f) is phased 2π(Δf/PFRi) apart from Ci(f), and

$$\int Ci'(f) \cdot Cj(f)df = \int Ci'(f) \cdot (1 - Cj(f))\, df;$$

an input binary data sequence is sequentially separated into multiple separate data sequences in a repeating cyclic order, and for each data of each separate data sequence, the phases or/and amplitudes of an i-th optical signal of the i-th optical frequency characteristic function and a j-th optical signal of the j-th optical frequency characteristic function are controlled in accordance with the value of said each piece of data, and the first and second optical signals thus obtained are combined by one or more light sources and transmitted therefrom as an optical code signal.

[0137] An example of the optical frequency characteristic function is a trigonometric function which has one and the same PFRi but whose Δf is PFRi/4 or – FSRi/4.

Another example of the function Ci(f) is a function which divides FSR into a continuous optical frequency portion which is a value L, into which FSR is divided by 2SNi which is twice larger than the product of arbitrary integer S and Ni, and which repeats Ni times making S consecutive optical frequencies in each L-long optical frequency portion have the intensity 1 and the succeeding S optical frequencies have the intensity 0,. or which

sequentially shifts the positions of the S consecutive optical frequencies of the intensity 1 by a predetermined amount.

[0138] The second mode of working of the invention is also applicable to the point-to-N point optical communication network PON shown in Figs. 2(a), 2(b), 3(a) and 3(b). It is also possible to apply to the third mode of working of the invention the technique of the first mode of working by which the i-th encoder on the monolithic planar lightwave circuit substrate controls the temperature of the planar lightwave circuit substrate which uses transmitted light through any one of the j-th decoders as described previously with reference to Figs. 15 and 28. Moreover, the optical encoding method of the first mode of working, which employs the arrayed waveguide AWG, described previously with reference to Figs. 21 and 22, is also applicable to the optical transmitter of the third mode of working.

[Third Mode of Working] [Reflective Optical Communication].

The third mode of working of the present invention is an application of the invention to a point-multipoint PON (Passive Optical Network) in which multiple subscriber terminals are connected to a central office via ~~an~~ optical fiber transmission lines, such an optical communications system as shown in Fig. 2 or 3.

[Embodiment 3-1]

A description will be given, with reference to Fig. 49, of the functional configuration of the basic concept of this third mode of working. Downstream signal light modulated (encoded) in accordance with binary data is input to a port 420a of an optical input/output unit 420 via an optical fiber 410 and then via an optical input/output port 412, thereafter being input to a switch 430 via a port 420b of the optical input/output unit 420. The switch 430 is controlled by an upstream data sequence from a terminal 431 to input

light are functions that bear such relationship as described below.

Let a function of the optical intensity for the optical frequency f when the downstream signal light is mark, a function of the optical intensity when the downstream signal light is space, a function of the optical intensity for the optical frequency f when the upstream signal light is mark, and a function of the optical intensity when the upstream signal light is space be represented by IM(f), IS(f), OM(f) and OS(f), respectively. The integration value of the product of the functions IM(f) and OM(f) with respect to f or summation of them and the integration value of the product of the functions IM(f) and OS(f) with respect to f or the summation of them are equal, and the integration value of the functions IS(f) and OM(f) with respect to f or the summation of them and the integral of the product of the functions IS(f) and OS(f) with respect to f or the summation of them are equal. That is, the functions bear the relationships that satisfy either one of the following equations (22) and (23) and either one of the following equations (24) and (25).

[0140]

$$\int IM(f)\, OM(f)\, df = \int IM(f)\, OS(f)\, df \qquad (22)$$

$$\Sigma IM(f)\, OM(f) = \Sigma IM(f)\, OS(f) \qquad (23)$$

$$\int IS(f)\, OM(f)\, df = \int IS(f)\, OS(f)\, df \qquad (24)$$

$$\Sigma IS(f)\, OM(f) = \Sigma IS(f)\, OS(f) \qquad (25)$$

In the above, $\int df$ means the above-mentioned integral for an interval of the optical frequency period of the downstream signal, and Σ means the above-mentioned summation for an interval of the optical frequency period of the downstream signal. The digital operations for Eqs. (22) and (24) are similar to the operations for Eqs. (23) and (25).

[0141] These relationships indicate that the optical intensity of the mark function and the optical intensity of the space function are equal to each other

and that components corresponding to a half of the frequency components forming the mark or space downstream signal light can be formed as mark or space upstream signal light. Accordingly, this optical transmitter is capable of outputting the upstream signal light modulated by the same optical power without lowering the modulation degree whether the downstream signal light be mark or space.

The above-mentioned functions may be such as shown in Fig. 6. Figs. 6(a) to (c) show examples of trigonometric functions, which are identical in amplitude, and overnormalized optical frequency period from 0 to 1 which is obtained through the optical frequency period from f0 to fL is normalized by the reference optical frequency f0 = fs, the numbers of repetition periods contained in this normalized optical frequency period are 1, 2 and 3, respectively; and one of the solid lines or broken lines phased $\pi/2$ apart, or the one-dot-chain line displaced about $\pi/4$ from the solid line as shown in Fig. 6(a) is used as the mark function and the function displaced π apart therefrom is used as the space function; and for different directions or different optical communication equipment, another function bearing the relation shown in Figs. 6 is used as the mark function and a function phased π apart therefrom is used as the space function. Alternatively, as shown in Fig. 50, the frequency period from f0 to fL (normalized frequencies 0 to 1) is divided into L chips (optical frequencies), and when the function shown in Fig. 50(a) is, for instance, the mark function, the space function has the same number of chips of intensity 1 as that of the mark function as shown in Fig. 50(b), and a half of the intensity-1 chips of mark or space function of the downstream signal light can be used for the upstream signal light. The first half of Fig. 50(b) is the same as the first half of Fig. 50(a), and the second half is an complementary version of the second half of Fig. 50(a). As an example

of each chip the

optical intensity is shown in triangular form, but it is desirable that the optical frequency characteristic of each chip be in flat rectangular form.

[0142] As an encoder in the case of using a trigonometric function as the filtering function of the mark or space encoder 440M or 440S, it is possible to use such a Mach-Zehnder interferometer as depicted in Fig. 7 which is composed of a pair of optical paths 41 and 42 of different path lengths and couplers 43 and 44 coupled to both ends of the optical paths. Fig. 51 shows an example of the configuration of an encoder for forming, as the filtering function of the mark or space function 440M or 440S, such a chip string as shown in Fig. 50. The input light is fed to an optical filter 5, and the optical filter 5 outputs optical frequency signals of respective chips to different ports and outputs optical components displaced an integral multiple of the optical frequency ΔF apart. For example, when the output light from the encoder 440M or 440S repeats the same pattern every four chips, components of optical frequencies $F_1 + q\Delta F$, $F_2 + q\Delta F$, $F_3 + q\Delta F$ and $F_4 + q\Delta F$ (where $q = 1, 2, \ldots$) are output from ports 1, 2, 3 and 4 of the optical filter 5, respectively. Of these outputs, the outputs from the ports corresponding to the chips of the intensity 1 are coupled by a coupler 6 and output therefrom. As such an optical filter 5, AWG (Arrayed Waveguide Grating) can be used as is the case with the filter 84 in Fig. 21.

[0143] The switch 430 provides the input light to the mark encoder 440M or space encoder 440S, depending on whether the data from the terminal 431 is mark or space. When the optical combiner 450 is formed by a switch that is controlled by the data from the input terminal 431, the switch 430 may be an optical splitter. The upstream signal light and the downstream signal light may be transmitted over different optical fibers. For example, as indicated by the broken line in Fig. 49, provision may be made to input the upstream

signal light by the optical intensity-frequency characteristic of the encoding function, and the decoder is decoding means which decodes and outputs, based on its decoding function, from the optical signal a component whose optical intensity-frequency characteristic is the decoding function.

[Embodiment 3-2]

Embodiment 3-2 is an example in which respective optical frequency characteristic functions made to be orthogonal to each other and to be chip codes. Referring to Fig. 53, Embodiment 3-2 will be described below. The downstream signal light from the optical fiber 410 is input to a downstream mark decoder 464M and a downstream space decoder 461S via the optical input/output port 412, then the optical input/output unit 420 and then optical splitters 421 and 422, and light having passed through these decoders 461M and 461S is converted by optical detectors 470M and 470S into electrical signals; these electrical signals are compared by a comparator 480 to detect, for example, the difference between them, and if the magnitude of the difference exceeds a predetermined value, it is provided as a downstream data sequence to an output terminal 481.

[0147] The other downstream signal light split by the first optical splitter 421 is input to the switch 430, and as shown in Fig. 49, it is modulated by the upstream data sequence from the input terminal 431 into the upstream signal light, which is fed to the optical input/output unit 420, from which it is output via the optical input/output port 412 to the optical fiber 410. When the optical combiner 450 is formed by a switch which is controlled by the data from the terminal 431, the switch 430 may be substituted with an optical splitter.

In Embodiment 3-1 an integration value of the product of the difference obtained by subtracting the space upstream signal light from the

mark upstream signal

light and the mark or space downstream signal light, with respect to an optical frequency, or the summation of them is zero; that is, the optical characteristic functions of them are made to apparently be orthogonal to each other. More specifically, the downstream signal light is a natural- number NI set of input light which has an optical frequency characteristic identical with the optical frequency function of either one of the mark and space; letting the optical intensity functions of the i-th mark and space be represented by IMi(f) and ISi(f), respectively, the relationship between the i-th downstream signal light and a j-th downstream signal light other than the i-th one both contained in the NI sets satisfies the following equation (26) or (27).

[0148] $\int IMi(f)(IMj(f) - ISj(f))\,df = \int ISi(f)(IMj(f) - ISj(f))\,df = \int IMj(f)(IMj(f) - ISi(f))\,df = \int ISj(f)\,(IMi(f) - ISj(f))\,df = 0$ (26)

$\Sigma IMi(f)(IMj(f) - ISj(f)) = \Sigma ISi(f)(IMj(f) - ISj(f)) = \Sigma IMj(f)(IMi(f) - ISi(f)) = \Sigma ISj(f)(IMi(F) - ISi(f)) = 0$ (27)

And, the relationship between the i-th downstream signal light and the i-th upstream signal light contained in the NI set satisfies the following equation (28) or (29).

[0149] $\int IMi(f)(OMi(f) - OSi(f))\,df = \int ISi(f)(OMi(f) - OSi(f))\,df = \int OMi(f)(IMi(f) - ISi(f))\,df = \int OSi(f)\,(IMi(f) - ISi(f))\,df = 0$ (28)

$\Sigma IMi(f)(OMi(f) - OSi(f)) = \Sigma ISi(f)(OMi(f) - OSi(f)) = \Sigma OMj(f)(IMi(f) - ISi(f)) = \Sigma OSi(f)(IMi(F) - ISi(f)) = 0$ (29)

In the above, $\int$ means the above-mentioned integral for an interval of the optical frequency period of the downstream signal, and Σ means the above-mentioned summation over the optical frequency period of the downstream signal. Incidentally, the downstream signal light to be detected in the same optical communication equipment and the upstream signal light to be output therefrom have different functions. The digital operations for Eqs.

the i-th filtering characteristic function IMi(f) is a function that repeats transmission of s chips and non-transmission of the succeeding s chips at least the number of times (n times) obtained by dividing L by 2s, and the i-th filtering characteristic function ISi(f) is a function that repeats non-transmission of s chips and transmission of the succeeding s chips at least the number of times (n times) obtained by dividing L by s. Incidentally, the illustrated functions start transmission or non-transmission of consecutive s chips at f0, but in such a case as shown in Fig. 54(c) where L = 6s and n = 3, the function may also be one that starts transmission or non-transmission of chips of an arbitrary integer s smaller than s, then repeats non-transmission or transmission of s chips and transmission or non-transmission of the succeeding s chips the number of times obtained by subtracting 1 from a number obtained by dividing L by 2s, followed by transmission or non-transmission of (s – s0) chips. That is, despite of the above-mentioned relationship, the function may be such a function as shown in Fig. 54(c) which is phased apart from the function of Fig. 54(b), for instance. The code 2 of the afore-mentioned second-order Hadamard matrix is L = 4, s = 1 and n = 2, the code 3 is L = 4, s = 2 and n = 1, and the code 4 is a cyclically left shifted version of the code 3 by the phase $\pi/4$. These relationships are the same as the characteristic functions shown in Embodiment 2-6 of the second mode of working of the invention; for example, IMj(f), ISi(f), OMj(f), and OSj(f) correspond to Ci(f), (1 – Ci(f)), Cj(f) and (1 – Cj(f)), respectively.

[0153] It will easily be seen that these filtering characteristics, the encoders 441M and 441S and the decoders 461M and 461S which have such functions can be similarly implemented by use of such optical filter 5 and couplers 6 and 6' as shown in Fig. 51. In the case of using the encoder of such a configuration as mentioned above, the upstream mark encoder 441M and the

an example of such optical communication equipment, in which insertable optical amplifiers are indicated by the broken lines and identified by the same reference numerals as those in Figs. 52, 53 and 57, and no description will be given of them. In this instance, the optical splitter 421 connected directly to the optical input/output port 412 is formed by an optical combiner/splitter, and in the case of selecting the mark signal light and the space signal light by controlling, according to data, the amplification factors of the optical amplifiers 452M and 452S connected to the sides opposite to the total reflectors 451M and 451S with respect to the mark encoder 441M and the space encoder 441S, the switch 430 is formed by an optical combiner/splitter. In the case where the mark encoder 441M and the space encoder 441S are formed by a single-structured encoder 441, the optical amplifiers 452M and 452S are inserted between the mark signal light output port and the space signal light output port of the encoder 441 and the total reflectors 451M and 451S, respectively, and in the case of controlling these optical amplifiers 452M and 452S according to the upstream data sequence, the input port of the encoder 441 is connected directly to the optical combiner/splitter 421, and consequently the optical combiner/splitter 430 can be omitted. In this case, the optical amplifiers 452M and 452S may be substituted with switches which are ON/OFF-controlled inversely to each other according to the upstream data; to sum up, they need only to select either one of the mark signal light and the space signal light in accordance with the upstream data.

[Embodiment 3-5]

While in the above the receiving decoder circuit for the downstream signal light and the transmitting encoder circuit for the upstream signal light are provided in parallel, they may be provided in tandem. Referring now to Fig. 59, Embodiment 3-5 will be described below in which the transmitting

the space signal light amplified by the optical detectors 471M and 471S are input to a correcting combiner 473 formed by a Mach-Zehnder interferometer having its port exchanged with that of the Mach-Zehnder interferometer forming the downstream decoder 461. The difference in the optical path length between the optical paths 41 and 42 in the downstream decoder 461 is corrected by the difference in the optical path length between the optical paths 41 and 42 in the correcting combiner 471, and the downstream mark signal light and the downstream space signal light are combined by the coupler 44 after passing through optical paths of the same length. The combined downstream signal light is input to the encoder 441 formed by the Mach-Zehnder interferometer. The other configurations and operations are the same as shown in Fig. 56. Since the optical outputs from the optical detectors 471M and 471S are combined by the Mach-Zehnder interferometer, the loss can be reduced as compared with that in the case of using the optical combiner 47 in Fig. 61.

[0164] Given below is a general description of the third mode of working of the invention. This mode of working is predicated on the optical communications system which: transmits the downstream signal light from the optical transmitter; receives the downstream signal light by reflective optical communication equipment; regenerates the downstream data sequence through utilization of part of the received downstream signal light; and modulates part of the received downstream signal light into the upstream signal light and transmits it to the above-mentioned optical transmitter.

The optical intensity-frequency characteristic of the received optical code signal has the function Ci(f) or Ck(f) and the filtering frequency characteristic of the

upstream encoder 441 is $Cj(f)$ or $Cm(f)$, and these functions satisfy the following equations that express the scalar-product integration values for the interval of an arbitrary source frequency width FSR contained in the optical frequency range from the optical frequency Fst to Fla.

$$\int Ci(f) \cdot Cj(f)\, df = \int Ci(f) \cdot Cm(f)\, df$$

$$\int Ck(f) \cdot Ci(f)\, df = \int Ck(f) \cdot Cm(f)\, df$$

[0165] Furthermore, at least one of the scalar-product integration values $\int Ci(f) \cdot Cj(f)\, df$ and $\int Ck(f) \cdot Ci(f)\, df$ is not zero. That is, either $Ci(f) > 0$ or $Ck(f) > 0$ holds.

Letting a common multiple of the repetition period PFRi of the function of each code in the optical frequency range from the optical frequency Fst to Fla be represented by the code length FCL and its natural-number multiple be represented by the optical frequency width FSR,

$$Ci(f) = Ci(f + PFRi), \text{ and}$$

$$\int Ci(f) \cdot Ci(f)\, df > \int Ci(f) \cdot (1 - Cj(f))\, df;$$

for the j-th optical frequency characteristic function $Cj(f)$ other than the i-th one,

$$\int Ci(f) \cdot Cj(f)\, df = \int Ci(f) \cdot (1 - Cj(f))\, df.$$

Based on the optical frequency characteristic functions bearing such relationships, for each piece of data of the binary data sequence the optical

CLAIM

[1] (Amended) An optical communications system using optical codes, characterized by:

an optical transmitter which:

emits from a light source an optical signal having an optical frequency width FSR contained in an optical frequency range from a predetermined optical frequency Fst to a predetermined optical frequency Fla; and

provides said optical signal to an encoder formed by at least one of filter means whose optical filtering characteristic is a function Ci(f) or its complementary function (1 – Ci(f)) both corresponding to an i-th code at least in said optical frequency range from the predetermined optical frequency Fst to the predetermined optical frequency Fla; and generates by and transmits from said encoder an optical code signal whose optical intensity-frequency characteristic is at least one of said function Ci(f) and its complementary function (1 – Ci(f)) of said i-th code corresponding to the value of each piece of data of said i-th binary data sequence, at least in the optical frequency width FSR constained in said optical frequency range from the predetermined optical frequency Fst to the predetermined optical frequency Fla;

wherein:

said function Ci(f) is a periodic function with an optical frequency f as a variable, expressed as Ci(f) = Ci(f + PFRi);

the optical frequency width FSR is an optical frequency width which is a common multiple of a repetition period PFRi of a function forming each code in said optical frequency range from the predetermined optical frequency Fst to the predetermined optical frequency Fla;

the complementary function of said function Ci(f) is a function obtained by subtracting said function Ci(f) from 1;

said function Ci(f) and said complementary function (1 – Ci(f)) bear the following relation:

$$\int Ci(f) \cdot Ci(f)\, df > \int Ci(f) \cdot (1 - Ci(f))\, df$$

where $\int df$ is a definite integral with respect to f for an arbitrary interval corresponding to said optical frequency width FSR constained in said optical frequency range from the optical frequency Fst to the optical frequency Fla; and

said function Ci(f), a function Cj(f) of an arbitrary j-th code other than said i-th code and the complementary function (1 – Cj(f)) of said function Cj(f) bear the following relation:

$$\int Ci(f) \cdot Cj(f) df = \int Ci(f) \cdot (1 - Cj(f)) df;$$ and

an optical receiver which includes:

at least optical filter means and an intensity detector for detecting the optical intensity of a received optical signal; and which:

generates from said received optical signal a first difference signal corresponding to the difference between a first intensity signal corresponding to the optical intensity of an optical signal whose optical intensity-frequency characteristic is $Ci(f)$ based on said function $Ci(f)$ and a second intensity signal corresponding to the optical intensity of an optical signal whose optical intensity-frequency characteristic is $(1 - Ci(f))$ based on said complementary function $(1 - Ci(f))$; and

regenerates said data sequence from said first difference signal.

[2] (Amended) The optical communications system of claim 1, characterized in that:

said repetition period PFRi is an optical frequency width obtained by dividing said optical frequency width FSR by an integer Ni corresponding to said function $Ci(f)$; and

let Δf represent the remainder of the division of an arbitrary optical frequency width equal to or narrower than said optical frequency width FSR by the repetition period PFRi of said function $Ci(f)$, let $2\pi(\Delta f/PFRi)$ represent a phase difference from said function $Ci(f)$, and let $Ci'(f)(= Ci(f + \Delta f))$ represent a function with an optical frequency $(f + \Delta f)$ different by said remainder Δf from the optical frequency of said function $Ci(f)$ of the i-th code;

said functions $Ci'(f)$, $Cj(f)$ and $(1 - Cj(f))$ bear the following relation:

$\int Ci'(f) \cdot Cj(f)df = \int Ci'(f) \cdot (1 - Cj(f))df$;

said encoder is formed by filter means whose optical filtering frequency characteristic is said function $Ci'(f)$ corresponding to each value of said remainder Δf transmittable in said optical frequency range from the predetermined optical frequency Fst to the predetermined optical frequency Fla;

said optical transmitter is a device which transmits as the optical code signal, an optical signal whose optical intensity-frequency characteristic is the function Ci'(f) of each value of said remainder Δf corresponding to the value of each piece of a binary data sequence, at least in the optical frequency width FSR; and

said optical receiver is a device which regenerates said binary data sequence from said first difference signal corresponding to each value of the remainder Δf which corresponds to the difference between: said first intensity signal generated from said received optical signal and corresponding to the optical intensity of said optical signal whose optical intensity-frequency characteristic is $Ci'(f)$ based on each function $Ci'(f)$ which corresponds to each value of the remainder Δf transmittable from said optical transmitter; and said second intensity signal generated from said received optical signal and corresponding to the optical intensity of said optical signal whose optical intensity-frequency characteristic is $(1 - Ci'(f))$ based on the complementary function $(1 - Ci'(f))$ corresponding to said function $Ci'(f)$ which corresponds to each value of the remainder Δf.

[3] (Amended) The optical communications system of claim 1, characterized in that:

said repetition period PFRi is an optical frequency width obtained by dividing said optical frequency width FSR by an integer Ni corresponding to said function $Ci(f)$; and

let Δf represent the remainder of the division of an optical frequency width equal to or narrower than said optical frequency width FSR by said period PFRi, let $2\pi(\Delta f/PFRi)$ represent a phase difference from the function $Ci(f)$, let said phase difference be set at $\pi/2$, and let $Ci'(f)(= Ci(f + \Delta f))$ represent a function with an optical frequency $(f + \Delta f)$ different by said remainder Δf from the optical frequency of said function $Ci(f)$ of said i-th code;

said functions $Ci'(f)$, $Cj(f)$ and $(1 - Cj(f))$ bear the following relation:

$$\int Ci'(f) \cdot Cj(f)df = \int Ci'(f) \cdot (1 - Cj(f))df;$$

said encoder is composed of: at least one of filter means whose optical

filtering frequency characteristic is said function Ci(f) or its complementary function (1 – Ci(f)) both corresponding to said i-th code in said optical frequency range from the predetermined optical frequency Fst to the predetermined optical frequency Fla; and additional filter means whose optical filtering characteristic is either at least one of said functions Ci'(f) and (1 – Ci'(f)), or at least one of said functions Cj(f) and (1 – Cj(f));

said optical transmitter is a device which: separates said binary data sequence by sequence converting means into a first separate data sequence and a second separate data sequence; generates and outputs, as the optical code signal from said encoder, an optical signal obtained by combining: a first optical signal whose optical intensity-frequency characteristic is either said function Ci(f) or (1 – Ci(f)) set by said first separate data sequence; and a second optical signal whose optical intensity-frequency characteristic is either at least one of said functions Ci'(f) and (1 – Ci'(f)), or at least one of said functions Cj(f) and (1 – Cj(f)) which correspond to the value of each piece of data of said second separate data sequence; and

said optical receiver is a device which: detects from said received optical signal a second difference signal corresponding to the difference between a third intensity signal corresponding to the optical intensity of said optical signal whose optical intensity-frequency characteristic is Ci'(f) or Cj(f) based on said function Ci'(f) or Cj(f) and a fourth intensity signal corresponding to the optical intensity of said optical signal whose optical intensity-frequency characteristic is (1 – Ci'(f)) or (1 – Cj(f)) based on the complementary function (1 – Ci'(f)) or (1 – Cj(f)) corresponding to said function Ci'(f) or Cj(f), respectively; and regenerates said first separate data sequence and said second separate data sequence from said second difference signal and said first difference signal.

[4] (Amended) The optical communications system of claim 3, characterized in that:

said optical transmitter has means for separating the input binary data sequence by said sequence converting means into a third separate data sequence and a fourth separate data sequence, in addition to said first and second separate data sequences, and includes:

amplitude changing means by which said first optical signal, which has its optical intensity-frequency characteristic set to be the

function Ci(f) or (1 – Ci(f)) according to the value of each piece of data of said first separate data sequence, and said second optical signal, which has its optical intensity-frequency characteristic set to be the function Ci'(f) or (1 – Ci'(f)), or the function Cj(f) or (1 – Cj(f)) according to the value of each piece of data of said second separated data sequence, are controlled to have optical intensities corresponding to the value of each piece of data of said third separate sequence and the value of each piece of data of said fourth separate data sequence, respectively; and

said optical receiver is a device which converts said first difference signal and said second difference signal into digital values, respectively, and regenerates said first, second, third and fourth separate data sequences from said digital values, respectively.

[5] (Amended) The optical communications system of claim 1, characterized in that:

said optical transmitter is a device which: receives an optical code signal whose optical frequency width is at least FSR and whose optical intensity-frequency characteristic is Cj(f) or (1 – Cj(f)); and multiplies said received optical code signal by at least one of said optical intensity-frequency characteristics Ci(f), (1 – Ci(f)), and zero in accordance with the value of each piece of data of said binary data sequence, and outputs said multiplied received optical code signal.

[6] (Amended) The optical communications system of any one of claims 1 to 5, characterized in that:

said period PFRi is an optical frequency width obtained by dividing said optical frequency width FSR by an integer Ni corresponding to said function Ci(f); said functions Ci(f) and Cj(f) have either the periods PFRi and PFRj different from each other, or periods PFRi and PFRj equal to each other,

in which case let Δf represent the remainder of the division of an optical frequency width equal to or narrower than said optical frequency width FSR by the repetition period PFRi of said function Ci(f), said function Cj(f) is Ci'(f) whose phase difference $2\pi(\Delta f/PFRi)$ from the function Ci(f) is $\pi/2$, and said function Ci(f) is a function containing a sine or cosine function.

[7] (Amended) The optical communications system of any one of claims 1 to 5, characterized in that:

said optical frequency width FSR is divided into chips by a value $V = 2Si \cdot Qi$ obtained by multiplying arbitrary integers Si and Qi both corresponding to said function Ci(f) by an integer 2; and said function Ci(f) is a function that repeats Qi times making consecutive Si chips have an optical intensity 1 and the succeeding Si chips have an optical intensity 0, or sequentially shifts the optical frequency positions of said consecutive Si chips of the optical intensity 1 by a predetermined value.

[8] (Amended) The optical communications system of any one of claims 1 to 5, characterized in that:

said optical communications system is a two-way communication system;

an optical transmitter of at least one side of said system is a device which generates an optical code signal by making an optical signal have an optical intensity-frequency characteristic by an encoder formed by at least one encoding optical filter whose optical filtering frequency characteristics are said optical filtering frequency function Ci(f) and its complementary function (1 – Ci(f)); and an optical receiver is a device which separates optical code signals whose optical intensity-frequency characteristics are Ci'(f) and (1 – Ci'(f)), or Cj(f) and (1 – Cj(f)) from a received optical signal by two decoding optical filters whose optical filtering characteristics are Ci'(f) and (1 – Ci'(f)),

or Cj(f) and (1 – Cj(f)), where Ci'(f)

is a function displaced a quarter period from Ci(f);

said at least one encoding optical filter and said two decoding optical filter are integrated on a monolithic planar lightwave circuit substrate; and

said optical communications system is provided with:

intensity detecting means for detecting the optical intensity of a transmitted optical signal from said at least one encoding optical filter or said two decoding optical filters; and

controlling means for controlling the temperature of said monolithic planar lightwave circuit substrate to maximize the optical intensity to be detected.

[9] (Amended) The optical communications system of any one of claims 1 to 5, characterized in that:

said optical receiver is a device which:

divides said received optical signal by filter means for each optical chip forming the code of the optical code signal;

detects, as a chip intensity signal, the optical intensity of each divided optical chip by an intensity detector; and

delays, by delay means, such detected chip intensity signals of said received optical signal corresponding to optical chips different in the time of arrival from transmission lines so that said optical chips arrive at the same time; and obtains the first difference signal by subtracting, by means of an intensity difference detector, the summation of those of said delayed chip intensity signals whose function (1 – Ci(f)) corresponds to 1 from the summation of those of said delayed chip intensity signals whose function Ci(f) corresponds to 1.

[10] (Amended) An optical transmitter, which:

emits from a light source an optical signal having an optical frequency

width FSR contained in an optical frequency range from a predetermined optical frequency Fst to a predetermined optical frequency Fla; and

provides said optical signal to an encoder formed by at least one of filter means whose optical filtering characteristic is a function Ci(f) or its complementary function (1 – Ci(f)) both corresponding to an i-th code at least in said optical frequency range from the predetermined optical frequency Fst to the predetermined optical frequency Fla; and generates by and transmits from said encoder an optical code signal whose optical intensity-frequency characteristic is at least one of said functions Ci(f) and (1 – Ci(f)) of said i-th code corresponding to the value of each piece of data of said i-th binary data sequence, at least in said optical frequency width FSR contained in said optical frequency range from the predetermined optical frequency Fst to the predetermined optical frequency Fla;

wherein:

said function Ci(f) is a periodic function with an optical frequency f as a variable, expressed as Ci(f) = Ci(f + PFRi);

the optical frequency width FSR is an optical frequency width which is a common multiple of a repetition period PFRi of a function forming each code in said optical frequency range from the predetermined optical frequency Fst to the predetermined optical frequency Fla;

the complementary function (1 – Ci(f)) of the function Ci(f) is a function obtained by subtracting said function Ci(f) from 1;

said functions Ci(f) and (1 – Ci(f)) bear the following relation:

$$\int Ci(f)\cdot Ci(f)df > \int Ci(f)\cdot(1 - Ci(f))df$$

where $\int df$ is a definite integral with respect to f for an arbitrary interval corresponding to said optical frequency width FSR contained in the optical frequency range from the optical frequency Fst to the optical

frequency Fla;

said function Ci(f), a function Cj(f) of an arbitrary j-th code other than the i-th code and the complementary function (1 – Cj(f)) of said function Cj(f) bear the following relation:

$$\int Ci(f) \cdot Cj(f)df = \int Ci(f) \cdot (1 - Cj(f))df.$$

[11] The optical transmitter of claim 10, characterized by the provision of:

N encoders for generating and outputting optical code signals whose optical intensity-frequency characteristics are different functions, respectively, said N

being an integer equal to or greater than 2; and

a combiner for combining and transmitting N sets of optical code signals.

[12] (Amended) The optical transmitter of claim 10 or 11, characterized in that:

letting a represent an integer value from 1 to a value N/2 by dividing the code number N by an integer 2, and letting r represent the remainder of division of 2, said function Ci(f) is as follows:

$(1 + \cos(2 \cdot \pi \cdot a \cdot f/FSR + r \cdot \pi/2))/2$.

[13] (Amended) The optical transmitter of claim 10 or 11, characterized in that:

said optical frequency width FSR is divided by an arbitrary integer R into chips; and

said functions Ci(f) and Cj(f) are composed of "1" and "−1" chips.

[14] (Amended) The optical transmitter of claim 10 or 11, characterized in that:

each encoder is provided with: a first modulation part for generating a first optical code signal whose optical intensity-frequency characteristic is a code function assigned to said encoder; a second modulation part for generating a second optical code signal whose optical intensity-frequency characteristic is the complementary function of the function of said first modulation part; and a switch which outputs therethrough at least one of said first and second optical code signals by use of one of two values for each piece of data of input binary data and outputs at least the other of said first and second optical code signals by use of the other of said two values for each piece of data of said input binary data.

[15] (Amended) The optical transmitter of claim 10, characterized in

that:

said repetition period PFRi is an optical frequency width obtained by dividing said optical frequency width FSR by an integer Ni corresponding to said function Ci(f); and

let Δf represent the remainder of the division of an arbitrary optical frequency width equal to or narrower than said optical frequency width FSR by the repetition period PFRi of said function Ci(f), let $2\pi(\Delta f/PFRi)$ represent a phase difference from said function Ci(f), and let $Ci'(f)(= Ci(f + \Delta f))$ represent a function with an optical frequency $(f + \Delta f)$ different by said remainder Δf from the optical frequency of said function Ci(f) of said i-th code;

said functions Ci'(f), Cj(f) and (1 – Cj(f)) bear the following relation: $\int Ci'(f) \cdot Cj(f)df = \int Ci'(f) \cdot (1 - Cj(f))df$;

said encoder is formed by filter means whose optical filtering frequency characteristic is said function Ci'(f) corresponding to each value of said remainder Δf transmittable at least in the range from the predetermined optical frequency Fst to the predetermined optical frequency Fla;

said optical transmitter is a device which transmits, for each piece of data of said binary data sequence, an optical signal whose optical intensity-frequency characteristic is said function Ci'(f) of the value of said remainder Δf corresponding to the value of each piece of data, as said optical code signal at least in said optical frequency width FSR; and

said optical transmitter includes:

a code modulation part which generates, for each piece of data of said binary data sequence, an optical code signal whose optical intensity-frequency characteristic is that one of functions satisfying the conditions for the above-said relation which differs only in the phase Δf in accordance with the value of each piece of data; and

a combiner for combining the optical code signals from said code modulation parts for outputting them as said output optical code signal.

[16] (Amended) The optical transmitter of claim 10, characterized in

that:

said period PFRi is an optical frequency width obtained by dividing said optical frequency width FSR by an integer Ni corresponding to said function Ci(f); let Δf represent the remainder of the division of an arbitrary optical frequency width equal to or narrower than said optical frequency width FSR by the repetition period PFRi of said function Ci(f), let $2\pi(\Delta f/PFRi)$ represent a phase difference from said function

$Ci(f)$, and let $Ci'(f)(= Ci(f + \Delta f))$ represent a function with an optical frequency $(f + \Delta f)$ different by the remainder Δf from the optical frequency of said function $Ci(f)$ of said i-th code; and

said functions $Ci'(f)$, $Cj(f)$ and $(1 - Cj(f))$ bear the following relation:

$\int Ci'(f) \cdot Cj(f)df = \int Ci'(f) \cdot (1 - Cj(f))df$;

let the phase difference be set at $\pi/2$;

said encoder is composed of: at least one of filter means whose optical filtering frequency characteristic is said functions $Ci(f)$ or $(1 - Ci(f))$ both corresponding to said i-th code in said optical frequency range from the predetermined optical frequency Fst to the predetermined optical frequency Fla; and additional filter means whose optical filtering characteristic is either at least one of said functions $Ci'(f)$ and $(1 - Ci'(f))$, or at least one of said functions $Cj(f)$ and $(1 - Cj(f))$; and

said optical transmitter is provided with:

a sequence converting part for separating said input binary data sequence into a first separate data sequence and a second separate data sequence;

a first modulation part for generating a first optical signal whose optical intensity-frequency characteristic is said function $Ci(f)$ or $(1 - Ci(f))$, depending on the value of each piece of data of said first separate data sequence;

a second modulation part for generating a second optical signal whose optical intensity-frequency characteristic is at least one of said functions $Ci'(f)$ and $(1 - Ci'(f))$, or at least one of said functions $Cj(f)$ and $(1 - Cj(f))$, depending on the value of each piece of data of said second separate data sequence; and

a combiner for combining said first and second optical signals for

outputting them as said optical code signal.

[17] (Amended) The optical transmitter of claim 16, characterized in that:

said sequence converting part is a converting part which converts the input binary data sequence into first, second, third and fourth separate data sequences;

said optical transmitter is provided with third and fourth modulation

parts for modulating said first and second optical signals into signals of optical intensities corresponding to the values of respective pieces of data of said third and fourth separate data sequences, respectively; and

said combiner combines said first and second optical signals of the light intensities corresponding to said values, respectively.

[18] (Amended) The optical transmitter of any one of claims 15 to 17, characterized in that:

said period PFRi is an optical frequency width obtained by dividing said optical frequency width FSR by an integer Ni corresponding to said function Ci(f); the periods of said functions Ci(f) and Cj(f) are the periods PFRi and PFRj different from each other, or periods PFRi and PFRj equal to each other, in which case let Δf represent the remainder of the division of an optical frequency width equal to or narrower than said optical frequency width FSR by the repetition period PFRi of said function Ci(f), said function Cj(f) is Ci'(f) whose phase difference $2\pi(\Delta f/PFRi)$ from the function Ci(f) is $\pi/2$, and said function Ci(f) is a function containing a sine or ~~a~~ cosine function.

[19] (Amended) The optical transmitter of any one of claims 15 to 17, characterized in that:

said optical frequency width FSR is divided into chips by a value $V = 2Si \cdot Qi$ obtained by multiplying arbitrary integers Si and Qi both corresponding to the function Ci(f) by an integer 2; and said function Ci(f) is a function that repeats Qi times making consecutive Si chips have an optical intensity 1 and the succeeding Si chips have an optical intensity 0, or sequentially shifts the optical frequency positions of said consecutive Si chips

of the optical intensity 1 by a predetermined value.

[20] The optical transmitter of any one of claims 15 to 17, characterized in that there are provided for each data sequence:

said light source;

an optical splitter for splitting an output optical signal from said light source into multiple optical signals;

optical filters of optical filtering characteristics having different code functions, for receiving said split optical signals;

an optical combiner for combining said optical signals transmitted through said optical filters and transmitting said combined output as an optical code signal; and

code modulating means which is inserted between said multiple optical filters and said optical splitter or optical combiner and controlled by one of said multiple data sequences, respectively.

[21] (Deleted)

[22] (Amended) An optical receiver characterized by:

filter means which permits the passage therethrough of an optical signal having an optical intensity-frequency characteristic based on a function at least in an optical frequency range from a predetermined optical frequency Fst to a predetermined optical frequency Fla;

intensity detecting means for detecting the optical intensity of said optical signal; and

means for adding together or subtracting intensity signals from each other; and

which is supplied with the received optical signal and regenerates data corresponding to the difference between: a first intensity signal corresponding to the optical intensity of an optical signal having an optical intensity-frequency characteristic Ci(f) based on a function Ci(f); and a second intensity signal corresponding to the optical intensity of an optical signal having an optical intensity-frequency characteristic (1 − Ci(f)) based on the complementary function (1 − Ci(f)) of said function Ci(f);

wherein:

said function Ci(f) is a periodic function expressed as Ci(f) = Ci(f + PFRi), the value of said function Ci(f) being in the range of 0 to 1;

an optical frequency width FSR is an optical frequency width which is a common multiple of a repetition period PFRi of a function forming each code in said optical frequency range from the predetermined optical frequency Fst to the predetermined optical frequency Fla;

said complementary function of the function Ci(f) is a function obtained by subtracting said function Ci(f) from 1;

said functions Ci(f) and (1 – Ci(f)) bear the following relation:

$$\int Ci(f) \cdot Ci(f)df > \int Ci(f) \cdot (1 - Ci(f))df$$

where $\int df$ is a definite integral with respect to f for an arbitrary interval corresponding to said optical frequency width FSR contained in said optical frequency range from the optical frequency Fst to the optical frequency Fla; and

said function Ci(f), a function Cj(f) of an arbitrary j-th code other than said i-th code and the complementary function (1 – Cj(f)) of said function Cj(f) bear the following relation:

$$\int Ci(f) \cdot Cj(f)df = \int Ci(f) \cdot (1 - Cj(f))df.$$

[23] (Amended) The optical receiver of claim 22, wherein:

said received optical signal is multiple optical code signals encoded to have optical intensity-frequency characteristics that satisfy orthogonality relations; and

said optical transmitter further comprising multiple decoders, each provided with:

a splitter which is supplied with and splits said received optical signal into multiple optical signals;

a first filter which is supplied with one of said received optical signals split by said splitter and whose optical filtering characteristic is Ci(f);

a first intensity detector which is supplied with the output from said first filter and detects its optical intensity as a first intensity signal;

a second filter which is supplied with one of said received optical signal and whose optical filtering characteristic is (1 – Ci(f));

a second intensity detector which is supplied with the output from said

second filter and detects its optical intensity as a second intensity signal; and

an intensity difference detector which is supplied with said first and second intensity signals and regenerates binary data based on the intensity difference obtained by subtracting the one from the other intensity signal, respectively;

wherein said functions Ci(f) and (1 – Ci(f)) differ between said multiple decoders.

[24] (Amended) The optical receiver of claim 22 or 23, characterized in that:

letting a represent an integer value in the range from 1 to N/2 obtained by dividing the code number N by an integer 2 and letting r represent the remainder of the division of 2, said function Ci(f) is as follows:

$(1 + \cos(2 \cdot \pi \cdot a \cdot f/FSR + r \cdot \pi/2))/2$.

[25] (Amended) The optical receiver of claim 22 or 23, wherein:

said optical frequency width FSR is divided by an arbitrary integer R into chips; and

said function Ci(f) and the function Cj(f) are composed of "1" and "–1" chips;

said optical receiver further comprising:

a filter which is supplied with said received optical signal and divides and outputs said received input signal for each chip;

multiple chip intensity detectors each of which is supplied with the output from said filter for each chip and detects the chip intensity signal corresponding to the optical intensity of said optical signal for each chip; and

an intensity difference detector which is supplied with the chip intensity signals from said multiple chip intensity detectors, and outputs binary data based on the summation of all the input chip intensity signals with

that signal corresponding to each "1" chip of said function Ci(f) held positive and that signal corresponding to each "1" chip of said function (1 – Ci(f)) held negative.

[26] (Amended) The optical signal receiver of claim 22, wherein:

said PFRi is an optical frequency width obtained by dividing said optical frequency width FSR by an integer Ni corresponding to said function Ci(f); and

let Δf represent the remainder of the division of an optical frequency width equal to or narrower than said optical frequency width FSR by said repetition period PFRi, let $2\pi(\Delta f/PFRi)$ represent a phase difference from the function Ci(f), and let Ci'(f)(= Ci(f + Δf)) represent a function with an optical frequency (f + Δf) different by said remainder Δf from the optical frequency of said function Ci(f) of said i-th code;

said functions Ci'(f), Cj(f) and (1 – Cj(f)) bear the following relation:

$\int Ci'(f) \cdot Cj(f)df = \int Ci'(f) \cdot (1 - Cj(f))df$;

said optical signal receiver further comprising:

a first filter which is supplied with said received optical signal and whose optical filtering frequency characteristic is said function Ci'(f) corresponding to each value of said remainder Δf transmittable from an optical transmitter of the communicating partner;

a second filter which is supplied with said received optical signal and whose optical filtering frequency characteristic is said function (1 – Ci'(f)) corresponding to said function Ci'(f) which corresponds to said each value of said remainder Δf;

a first intensity detectors which are supplied with the output from said first filters and detect a first intensity signals corresponding to the optical

intensities of the output from said first filters;

a second intensity detectors which are supplied with the output from said second filters and detect a second intensity signals corresponding to the optical intensities of the output from said second filters; and

means which are supplied with said first and second intensity signals, detect the difference therebetween, and regenerate and outputs said binary data sequence.

[27] (Amended) The optical receiver of claim 22, wherein:

said PFRi is an optical frequency width obtained by dividing said optical frequency width FSR by an integer Ni corresponding to said function Ci(f); and

let Δf represent the remainder of the division of an optical frequency width equal to or narrower than said optical frequency width FSR by the repetition period PFRi of said function Ci(f), let $2\pi(\Delta f/PFRi)$ represent a phase difference from said function Ci(f), let $Ci'(f)(= Ci(f + \Delta f))$ represent a function with an optical frequency $(f + \Delta f)$ different by said remainder Δf from the optical frequency of said function Ci(f) of said i-th code, and let said phase difference be set at $\pi/2$;

said functions Ci'(f), Cj(f) and $(1 - Cj(f))$ bear the following relation:

$$\int Ci'(f) \cdot Cj(f)df = \int Ci'(f) \cdot (1 - Cj(f))df;$$

said optical receiver further comprising:

a first filter which is supplied with said received optical signal and whose optical filtering frequency characteristic is said function Ci(f);

a second filter which is supplied with said received optical signal and whose optical filtering frequency characteristic is said function $(1 - Ci(f))$;

a first intensity detector which is supplied with the output from said first filter and detects a first intensity signal corresponding to the optical

intensity of the output from said first filter;

a second intensity detector which is supplied with the output from said

second filter and detects a second intensity signal corresponding to the optical intensity of the output from said second filter;

a third filter which is supplied with said received optical signal and whose optical filtering frequency characteristic is said function Ci'(f) or Cj(f);

a fourth filter which is supplied with said received optical signal and whose optical filtering frequency characteristic is said function (1 – Ci'(f)) or (1 – Cj(f));

a third intensity detector which is supplied with the output from said third filter and detects a third intensity signal corresponding to the optical intensity of the output from said third filter;

a fourth intensity detector which is supplied with the output from said fourth filter and detects a fourth intensity signal corresponding to the optical intensity of the output from said fourth filter;

a first subtractor which is supplied with said first and second intensity signals and outputs the difference therebetween as a first difference signal;

a second subtractor which is supplied with said third and fourth intensity signals and outputs the difference therebetween as a second difference signal; and

data generating means which is supplied with said first and second difference signals and outputs said binary data sequence.

[28] The optical receiver of claim 27, characterized in that:

said data generating means is means which renders said first difference signal into first binary data and said second difference signal into second binary data, and arranges said first and second binary data in a sequential order to form said binary data sequence.

[29] The optical receiver of claim 27, characterized in that:

said data generating means is provided with:

a first A/D converter for converting said first difference signal to a first digital;

a second A/D converter for converting said second difference signal to a second digital; and

binary sequencing means which is supplied with said first and second digital signals, and outputs that one of predetermined combinations of four or more pieces of data 0 or 1 for a combination of the values of said input digital signals.

[30] (Amended) The optical receiver of any one of claims 26 to 29, characterized in that:

said functions Ci(f) and Cj(f) have either the periods PFRi and PFRj different from each other, or periods PFRi and PFRj equal to each other, in which case let Δf represent the remainder of the division of an optical frequency width equal to or narrower than said optical frequency width FSR by the repetition period PFRi of said function Ci(f), and said function Cj(f) is Ci'(f) (= Ci(f ± π/2) whose phase difference 2π(Δf/PFRi) from said function Ci(f) is π/2.

[31] (Amended) The optical receiver of any one of claims 26 to 29, wherein:

said optical frequency width FSR is divided into chips by a value V = 2Si · Qi obtained by multiplying arbitrary integers Si and Qi both corresponding to said function Ci(f) by an integer 2; and

said functions Ci(f) and Cj(f) are composed of "1" and "−1" chips;

said optical receiver further comprising:

a filter which is supplied with said received optical signal and divides and outputs said received input signal for each chip;

multiple chip intensity detectors each of which is supplied with the filter output for each chip and detects the chip intensity signal corresponding to the optical intensity of said optical signal for each chip; and

an intensity difference detector which is supplied with the chip intensity signals from said multiple chip intensity detectors, and outputs binary data based on the summation of all the input chip intensity signals with that signal corresponding to each "1" chip of said function Ci(f) held positive and that signal corresponding to each "1" chip of said function (1 – Ci(f)) held negative.

[32] (Amended) Reflective optical communication equipment which is supplied with a received optical signal and a binary data sequence, modulates the received optical signal to an optical signal whose optical intensity-frequency characteristic is a function with an optical frequency f as a variable, and transmits the modulated optical signal, and which is characterized by:

an encoder which is supplied with said received optical signal of at least an optical frequency width FSR contained in an optical frequency range from a predetermined optical frequency Fst to a predetermined optical frequency Fla and outputs an optical signal filtered by optical filter means whose optical filtering frequency characteristic is a first function Ci(f) in said optical frequency range;

a complementary encoder which is supplied with said received optical signal and outputs a complementary optical signal filtered by optical filter means whose optical frequency characteristic is the complementary function

(1 – Ci(f)) in said optical frequency range; and

selective combining means which selectively combines, according to the value of each piece of data, the output optical signal from said encoder and the complementary

optical signal from said complementary encoder, and transmits them as an optical code signal;

wherein:

said function Ci(f) is a periodic function expressed as $Ci(f) = Ci(f + PFRi)$, the value of said function Ci(f) being in the range of 0 to 1;

said optical frequency width FSR is an optical frequency width which is a common multiple of a repetition period PFRi of a function forming each code in said optical frequency range from the predetermined optical frequency Fst to the predetermined optical frequency Fla;

the complementary function of said function Ci(f) is a function obtained by subtracting said function Ci(f) from 1;

said functions Ci(f) and (1 – Ci(f)) bear the following relation:

$$\int Ci(f) \cdot Ci(f)df > \int Ci(f) \cdot (1 - Ci(f))df$$

where $\int df$ is a definite integral with respect to f for an arbitrary interval corresponding to said optical frequency width FSR contained in said optical frequency range from the optical frequency Fst to the optical frequency Fla; and

said function Ci(f), a function Cj(f) of an arbitrary j-th code other than said i-th code and the complementary function (1 – Cj(f)) of said function Cj(f) bear the following relation:

$$\int Ci(f) \cdot Cj(f)df = \int Ci(f) \cdot (1 - Cj(f))df.$$

[33] The reflective optical communication equipment of claim 32, which is characterized by:

a decoder which is supplied with said received optical signal and whose optical filtering frequency characteristic is said function Cj(f));

a complementary decoder which is supplied with said received optical signal and whose optical filtering frequency characteristic is said function (1

$- Cj(f));$

a first optical detector which is supplied with the output light from said decoder and outputs an intensity signal corresponding to the optical intensity of the output light from said decoder;

a complementary optical detector which is supplied with the output light from said complementary decoder and outputs a complementary intensity signal corresponding to the optical intensity of the output light from said complementary decoder; and

a comparator which is supplied with said intensity signal and said complementary intensity signal and outputs one of two pieces of data in accordance with the level difference between said intensity signals when the difference exceeds a predetermined value.

[34] (Amended) The reflective optical communication equipment of claim 33, characterized in that said selective combining means is provided with: a total reflector and a complementary total reflector for totally reflecting said received optical signal, respectively; and selectors and complementary selectors disposed between said encoder and said total reflector and between said complementary encoder and said complementary total reflector, respectively, for selecting either one of said optical signal and an optical signal complementary thereto in accordance with the value of input data.

[35] The reflective optical transmission equipment of claim 33, which is characterized by:

optical amplifiers for use as said optical detector and said complementary optical detector for optically amplifying the input optical signals thereto and outputting the amplified optical signals and intensity signals corresponding to the optical intensities of said input optical signals; and

an optical combiner for combining the amplified optical signals from

said optical detector and said complementary optical detector and inputting

the combined optical signal as said received optical signal to said encoder and said complementary encoder.

[36] The reflective optical communication equipment of claim 33, which is characterized by:

a switch for selecting said optical signal or complementary optical signal in accordance with the value of input data;

an optical combiner/splitter which is supplied with the output from said switch, splits said output into two, and inputs one of them to said decoder and said complementary decoder; and

a total reflector which is supplied with the other split light from said optical combiner/splitter and totally reflects the input light.

[37] The reflective optical communication equipment of claim 33, characterized by:

a switch for selecting said optical signal or said complementary optical signal in accordance with the value of input data; and

a partial reflector which is supplied with the output light from said switch, reflects a portion of the output light and inputs the remaining portion of said output light to said decoder and said complementary decoder.

[38] (Amended) The reflective optical communication equipment of any one of claims 33 to 37, characterized in that:

said period PFRi is an optical frequency width obtained by dividing said optical frequency width FSR by an integer Qi corresponding to said function Ci(f); let Δf represent the remainder of the division of an optical frequency width equal to or narrower than said optical frequency width FSR by the repetition period PFRi of the function Ci(f); said functions Ci(f) and Cj(f) have either the periods PFRi and PFRj different from each other or periods PFRi and PFRj equal to each other; said function Cj(f) is Ci'(f) whose

phase difference $2\pi(\Delta f/PFRi)$ from said function Ci(f) is $\pi/2$; and said function Ci(f) is a trigonometric function;

said encoder and said complementary encoder are integrated as an output encoder; and said decoder and said complementary decoder are integrated as an input decoder.

[39] (Amended) The reflective optical communication equipment of any one of claims 33 to 37, characterized in that:

said optical frequency width FSR is divided into chips by a value $V = 2Si \cdot Qi$ obtained by multiplying arbitrary integers Si and Qi both corresponding to said function Ci(f) by an integer 2; and said function Ci(f) is a function that repeats Qi times making consecutive Si chips have an optical intensity 1 and the succeeding Si chips have an optical intensity 0, or sequentially shifts the optical frequency positions of said consecutive Si chips of the optical intensity 1 by a predetermined value;

said encoder and said complementary encoder are integrated as an output encoder; and said decoder and said complementary decoder are integrated as an input decoder.

[40] (Added) An optical communications system using optical codes, characterized by:

an optical transmitter provided with:

multiple light sources for emitting optical signals of optical frequencies corresponding to MU = V chips each having a chip width that is a unit optical frequency width into which an optical frequency width FSR contained in an optical frequency range from a predetermined optical frequency Fst to a predetermined optical frequency Fla is divided by a natural number M and an integer U equal to or greater than 3;

drive signal generators for generating drive signals for said multiple

light sources;

an optical combiner for combining the output lights from said multiple light sources and outputting the combined light as an optical code signal; and

code modulating means which is inserted between said multiple light sources and said drive signal generators or said optical combiner and controlled by each piece of data of an i-th binary data sequence to make said optical code signal have an optical intensity-frequency characteristic based on at least one of said i-th code function Ci(f) and its complementary function (1 – Ci(f));

wherein:

said optical frequency width FSR is an optical frequency width which is a common multiple of a repetition period PFRi of a function forming each code in said optical frequency range from the predetermined optical frequency Fst to the predetermined optical frequency Fla;

said complementary function of the function Ci(f) is a function obtained by subtracting said function Ci(f) from 1;

said functions Ci(f) and (1 – Ci(f)) bear the following relation:

$$\int Ci(f) \cdot Ci(f)df > \int Ci(f) \cdot (1 - Ci(f))df$$

where $\int df$ is a definite integral with respect to f for an arbitrary interval corresponding to said optical frequency width FSR contained in said optical frequency range from the optical frequency Fst to the optical frequency Fla; and

said function Ci(f), a function Cj(f) of an arbitrary j-th code other than said i-th code and the complementary function (1 – Cj(f)) of said function Cj(f) bear the following relation:

$$\int Ci(f) \cdot Cj(f)df = \int Ci(f) \cdot (1 - Cj(f))df; \text{ and}$$

an optical receiver which includes:

at least optical filter means and an intensity detector for detecting the optical intensity of the optical signal received by said optical receiver; and which:

generates from said received optical signal a first difference signal corresponding to the difference between a first intensity signal corresponding to the optical intensity of an optical signal whose optical intensity-frequency characteristic is Ci(f) and a second intensity signal corresponding to the optical intensity of an optical signal whose optical intensity-frequency characteristic is (1 – Ci(f)); and regenerates said data sequence from said first difference signal.

[41] (Added) The optical communications system of claim 40, characterized in that:

the chip number Pi of the period PFRi of said function Ci(f) is the number of chips forming the optical frequency width obtained by dividing the chip number V of said optical frequency width FSR by an integer Ni corresponding to said function Ci(f);

let Δf represent the remainder of the division of an arbitrary chip number equal to or smaller than V by said chip number Pi of the repetition period PFRi of said function Ci(f), let $2\pi(\Delta f/Pi)$ represent a phase difference from said function Ci(f), and let Ci'(f) (=Ci(f + Δ)) represent a function with an optical frequency different by said remainder Δf from the optical frequency of said function Ci(f) of said i-th code;

said functions Ci'(f), Cj(f) and (1 – Cj(f)) bear the following relation:

$\int Ci'(f) \cdot Cj(f)df = \int Ci'(f) \cdot (1 - Cj(f))df$;

the control by said code modulating means is to make the optical intensity-frequency characteristic of said optical code signal have the function Ci'(f) corresponding to each value of said remainder Δf that can be

transmitted;

said optical transmitter is a device which transmits as said optical code signal, an optical signal whose optical intensity-frequency characteristic is the function Ci'(f) of the value of said remainder Δf corresponding to the value of each piece of binary data sequence, at least in the optical frequency width FSR; and

said optical receiver is a device which regenerates said data sequence from each first difference signal corresponding to each value of said remainder Δf which corresponds to the difference between: said first intensity signal generated from said received optical signal and corresponding to the optical intensity of the optical signal whose optical intensity-frequency characteristic is Ci'(f) based on each function Ci'(f) which corresponds to each value of said remainder Δf transmittable by said optical transmitter; and said second intensity signal generated from said received optical signal and corresponding to the optical intensity of the optical signal whose optical intensity-frequency characteristic is (1 − Ci'(f)) based on the complementary function (1 − Ci'(f)) corresponding to said function Ci'(f) which corresponds to the value of said remainder Δf.

[42] (Added) The optical communications system of claim 40, characterized in that:

the chip number Pi of the period PFRi of said function Ci(f) is the number of chips forming the optical frequency width obtained by dividing the chip number V of said optical frequency width FSR by an integer Ni corresponding to said function Ci(f);

let Δf represent the remainder of the division of a chip number equal to or smaller than V by said chip number Pi of the repetition period PFRi of said function Ci(f), let 2π(Δf/Pi) represent a phase difference from said

function $Ci(f)$, let the phase difference be set at $\pi/2$, and let $Ci'(f)$ ($=Ci(f+\Delta f)$) represent a function with an optical frequency ($f+\Delta f$) different by said remainder Δf from the optical frequency of said function $Ci(f)$ of said i-th code;

said functions $Ci'(f)$, $Cj(f)$ and $(1-Cj(f))$ bear the following relation:

$$\int Ci'(f)\cdot Cj(f)df = \int Ci'(f)\cdot(1-Cj(f))df;$$

said code modulating means is means which selectively controls each chip to have the 1 or 0 level in accordance with a function;

said code modulating means is means which generates a first optical signal whose optical intensity-frequency characteristic is at least one of said function $Ci(f)$ and its complementary function $(1-Ci(f))$ both corresponding to said i-th code and a second optical signal whose optical intensity-frequency characteristic is at least one of said function $Ci'(f)$ and said complementary function $(1-Ci'(f))$, or at least one of said functions $Cj(f)$ and $(1-Cj'(f))$;

said optical transmitter is a device which: separates said binary data sequence by sequence converting means into a first separate data sequence and a second separate data sequence; combines the first optical signal whose optical intensity-frequency characteristic is said function $Ci(f)$ or $(1-Ci(f))$ set by said first separate data sequence and the second optical signal whose optical intensity-frequency characteristic is at least one of said functions $Ci'(f)$ and $(1-Ci'(f))$, or at least one of said functions $Cj(f)$ and $(1-Cj(f))$ corresponding to the value of each piece of data of said second separate data sequence; and outputs the combined optical signal as said optical code signal; and

said optical receiver is a device which: detects from its received optical signal, a second difference signal corresponding to the difference between a third intensity signal corresponding to the optical intensity of the

optical signal whose optical intensity-frequency characteristic is Ci'(f) or Cj(f) based on said function Ci'(f) or Cj(f) and a fourth intensity signal corresponding to the optical signal whose optical intensity-frequency characteristic is (1 – Ci'(f)) or (1 – Cj(f)) based on said complementary function (1 – Ci'(f)) or (1 – Cj(f)), respectively; and regenerates said first separate data sequence and said second separate data sequence from said first difference signal and said second difference signal, respectively.

[43] (Added) The optical communications system of claim 42, characterized in that:

said optical transmitter has means for separating the input binary data sequence by said sequence converting means into a third separate data sequence and a fourth data sequence, in addition to said first and second separate data sequences, and includes:

amplitude changing means by which said first optical signal which has its optical intensity-frequency characteristic set to be the function Ci(f) or (1 – Ci(f) according to the value of each piece of data of said first separate data sequence and said second optical signal which has its optical intensity-frequency characteristic set to be the function Ci'(f) or (1 – Ci'(f)), or the function Cj(f) or (1 – Cj(f)) according to the value of each piece of data of said second separate data sequence, are controlled to have optical intensities corresponding to the value of each piece of data of said third separate data sequence and the value of each piece of data of said fourth separate data sequence, respectively; and

said optical receiver is a device which converts said first and second difference signals into digital values, respectively, and regenerates said first, second, third and fourth separate data sequences from said digital values, respectively.

[44] (Added) The optical communications system of any one of claims 40 to 43, characterized in that:

the chip number V for dividing said optical frequency width FSR is a value 2Si·Qi obtained by multiplying arbitrary integers Si and Qi both corresponding to said function Ci(f) by an integer 2; and said function Ci(f) is a function that repeats Qi times making consecutive Si chips have an optical intensity 1 and the succeeding Si chips have an optical intensity 0, or sequentially shifts the optical frequency positions of said consecutive Si chips of optical intensity 1 by a predetermined value.

[45] (Added) The optical communications system of any one claims 40 to 43, characterized in that:

said optical receiver is a device which:

divides said received optical signal by filter means for each optical chip forming the code of the optical code signal;

detects, as a chip intensity signal, the optical intensity of each divided optical chip by an intensity detector; and

delays, by delay means, such detected chip intensity signals of said received optical signal corresponding to optical chips different in the time of arrival from transmission lines so that said optical chips arrive at the same time; and obtains the first difference signal by subtracting, by means of an intensity difference detector, the summation of those of said delayed chip intensity signals whose function (1 – Ci(f)) corresponds to 1 from the summation of those of said delayed chip intensity signals whose function Ci(f) corresponds to 1.

[46] (Added) An optical transmitter, comprising:

multiple light sources for emitting optical signals of optical frequencies corresponding to MU = V chips each having a chip width that is a

unit optical frequency width into which an optical frequency width FSR contained in an optical frequency range from a predetermined optical frequency Fst to a predetermined optical frequency Fla is divided by a natural number M and an integer U equal to or greater than 3;

drive signal generators for generating drive signals for said multiple light sources;

an optical combiner for combining the output light from said multiple light sources and outputting it as an optical code signal; and

code modulating means which is inserted between said multiple light sources and said drive signal generators or said optical combiner and controlled by each piece of data of an i-th binary data sequence to make said optical code signal have an optical intensity-frequency characteristic based on at least one of said i-th code function Ci(f) and its complementary function (1 – Ci(f));

wherein:

said optical frequency width FSR is an optical frequency width which is a common multiple of a repetition period PFRi of a function forming each code in said optical frequency range from the predetermined optical frequency Fst to the predetermined optical frequency Fla;

the complementary function of said function Ci(f) is a function obtained by subtracting said function Ci(f) from 1;

said functions Ci(f) and (1 – Ci(f)) bear the following relation:

$$\int Ci(f) \cdot Ci(f)df > \int Ci(f) \cdot (1 - Ci(f))df$$

where $\int df$ is a definite integral with respect to f for an arbitrary interval corresponding to said optical frequency width FSR contained in said optical frequency range from the optical frequency Fst to the optical frequency Fla; and

said function Ci(f), a function Cj(f) of an arbitrary j-th code other than said i-th code and the complementary function (1 – Cj(f)) of the said function Cj(f) bear the following relation:

$$\int Ci(f) \cdot Cj(f)df = \int Ci(f) \cdot (1 - Cj(f))df.$$

[47] (Added) The optical transmitter of claim 46, characterized by the provision of:

N sets of light sources and drive signal generators for generating and outputting optical code signals having optical intensity-frequency characteristics of different functions, respectively, said N being an integer equal to or greater than 2; and

a combiner for combining and transmitting N sets of optical code signals.

[48] (Added) The optical transmitter of claim 46 or 47, characterized in that:

said functions Ci(f) and Cj(f) are each composed of "1" and "–1" chips.

[49] (Added) The optical transmitter of claim 46 or 47, characterized in that:

each code modulating means is provided with: a first modulation part for generating a first optical code signal whose optical intensity-frequency characteristic is a code function assigned to said encoder; a second modulation part for generating a second optical code signal whose optical intensity-frequency characteristic is the complementary function of said function of said first modulation part; and a switch which outputs therethrough at least one of said first and second optical code signals by use of one of two values for each piece of data of input binary data and outputs at least the other of said first and second optical code signals by use of the other

of said two values for each piece of data of said input binary data.

[50] (Added) The optical transmitter of claim 46, characterized in that:

the chip number Pi of the period PFRi of said function Ci(f) is the number of chips forming the optical frequency width obtained by dividing the chip number V of said optical frequency width FSR by an integer Ni corresponding to said function Ci(f);

let Δf represent the remainder of the division of an arbitrary chip number equal to or smaller than V by the chip number Pi of the repetition period PFRi of said function Ci(f), let $2\pi(\Delta f/Pi)$ represent a phase difference from said function Ci(f), and let Ci'(f) (=Ci(f + Δf)) represent a function with an optical frequency (f + Δ) different by said remainder Δf from the optical frequency of said function Ci(f) of said i-th code;

said functions Ci'(f), Cj(f) and (1 – Cj(f)) bear the following relation:

$$\int Ci'(f) \cdot Cj(f)df = \int Ci'(f) \cdot (1 - Cj(f))df;$$

the control by said code modulating means is to make the optical intensity-frequency characteristic of said optical code signal have said function Ci'(f) corresponding to each value of said remainder Δf that can be transmitted;

said optical transmitter is a device which transmits, for each piece of data of said binary data sequence, as said optical code signal, an optical signal whose optical intensity-frequency characteristic is said function Ci'(f) of the value of said remainder Δf corresponding to the value of each piece of data, at least in said optical frequency width FSR, and which includes:

a code modulation part which generates, for each piece of data of said binary data sequence, an optical code signal whose optical intensity-frequency characteristic is that one of functions satisfying the conditions for the above-said relation which differs only in the phase Δf in accordance with the

value of each piece of data; and

a combiner for combining the optical code signals from said code modulation parts and outputting the combined signal as the output optical code signal.

[51] (Added) The optical transmitter of claim 46, characterized in that:

the chip number Pi of the period PFRi of said function Ci(f) is the number of chips forming the optical frequency width obtained by dividing the chip number V of said optical frequency width FSR by an integer Ni corresponding to the function Ci(f);

let Δf represent the remainder of the division of a chip number equal to or smaller than V by the chip number Pi of the repetition period PFRi of said function Ci(f), let $2\pi(\Delta f/Pi)$ represent a phase difference from said function Ci(f), and let Ci'(f) (=Ci(f + Δf)) represent a function with an optical frequency (f + Δ) different by said remainder Δf from the optical frequency of said function Ci(f) of said i-th code;

said functions Ci'(f), Cj(f) and (1 – Cj(f)) bear the following relation:

$\int Ci'(f) \cdot Cj(f)df = \int Ci'(f) \cdot (1 - Cj(f))df$;

let the phase difference be set at $\pi/2$;

said code modulating means is means which generates a first optical signal whose optical frequency characteristic is said function Ci(f) or (1 – Ci(f)) both corresponding to said i-th code and a second optical signal whose optical frequency characteristic is at least one of said functions Ci'(f) and (1 – Ci'(f)), or at least one of said functions Cj(f) and (1 – Cj(f)); and

said optical transmitter is provided with:

a sequence converting part which separates said input binary data sequence into a first separate data sequence and a second separate data sequence;

a first modulation part which generates a first optical signal whose optical intensity-frequency characteristic is said function Ci(f) or (1 – Ci(f)), depending on the value of each piece of data of said first separate data sequence;

a second modulation part which generates a second optical signal whose optical intensity-frequency characteristic is at least one of said functions Ci'(f) and (1 – Ci'(f)), or at least one of said functions Cj(f) and (1 – Cj'(f)), depending on the value of each piece of data of said second separate data sequence; and

a combiner for combining said first and second optical signals and outputs the combined signal as the optical code signal.

[52] (Added) The optical transmitter of claim 51, characterized in that:

said sequence converting part is a converting part which converts said input binary data sequence into, first, second, third and fourth separate data sequences;

said optical transmitter is provided with third and fourth modulation parts for modulating said first and second optical signals into signals of optical intensities corresponding to the values of respective pieces of data of said third and fourth separate data sequences; and

said combiner is a combiner for combining said first and second optical signals of the light intensities corresponding to said values, respectively.

[53] (Added) The optical transmitter of any one of claims 50 to 52, characterized in that

the chip number V for dividing said optical frequency width FSR is a value 2Si·Qi obtained by multiplying arbitrary integers Si and Qi both corresponding to said function Ci(f) by an integer 2; and said function Ci(f) is

a function that repeats Qi times making consecutive Si chips have an optical intensity 1 and makes the succeeding Si chips have an optical intensity 0, or sequentially shifts the optical frequency positions of said consecutive Si chips of the optical intensity 1 by a predetermined value.

FIG. 13(a)

FIG. 13(b)

FIG. 13(c)

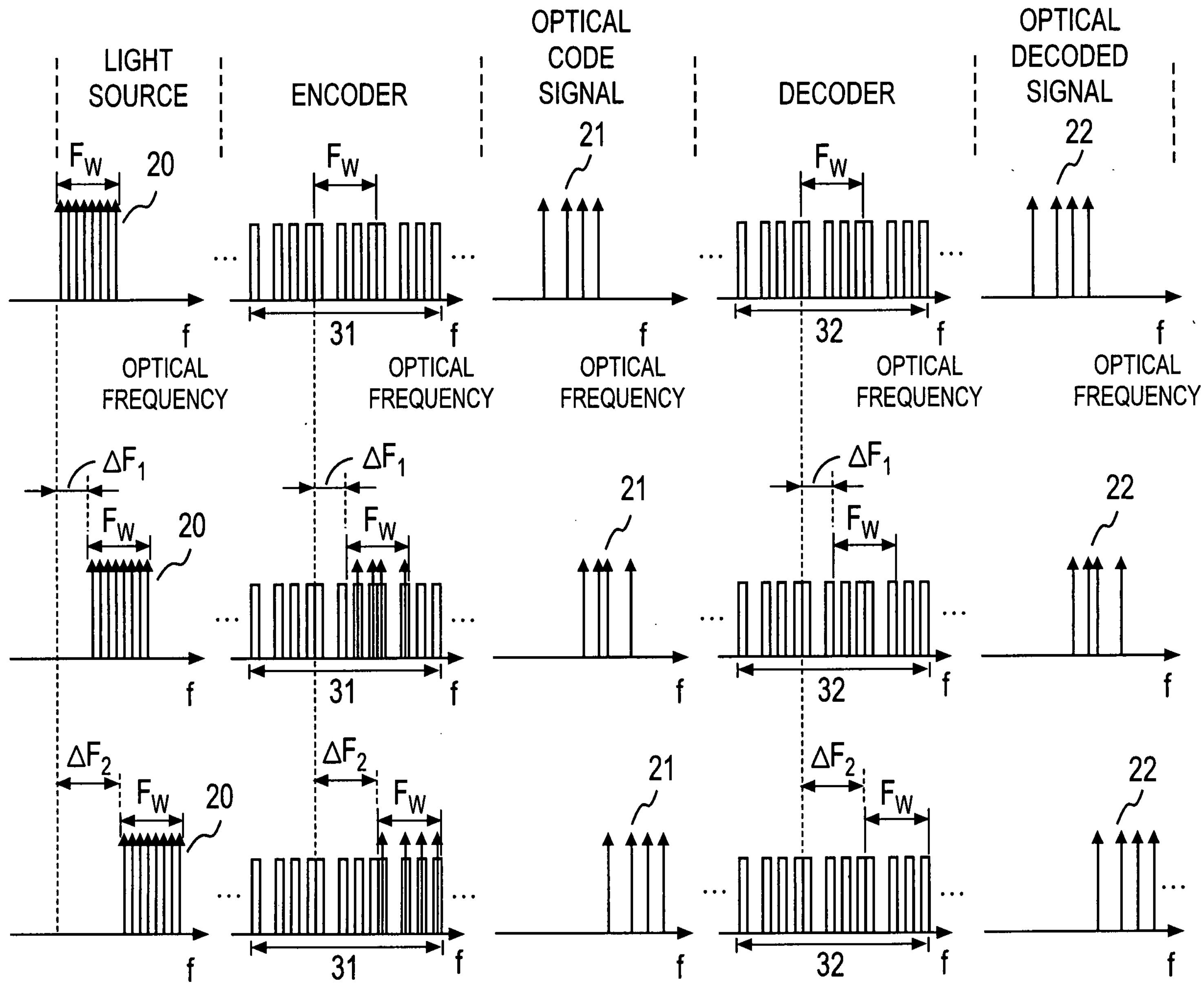


FIG. 18

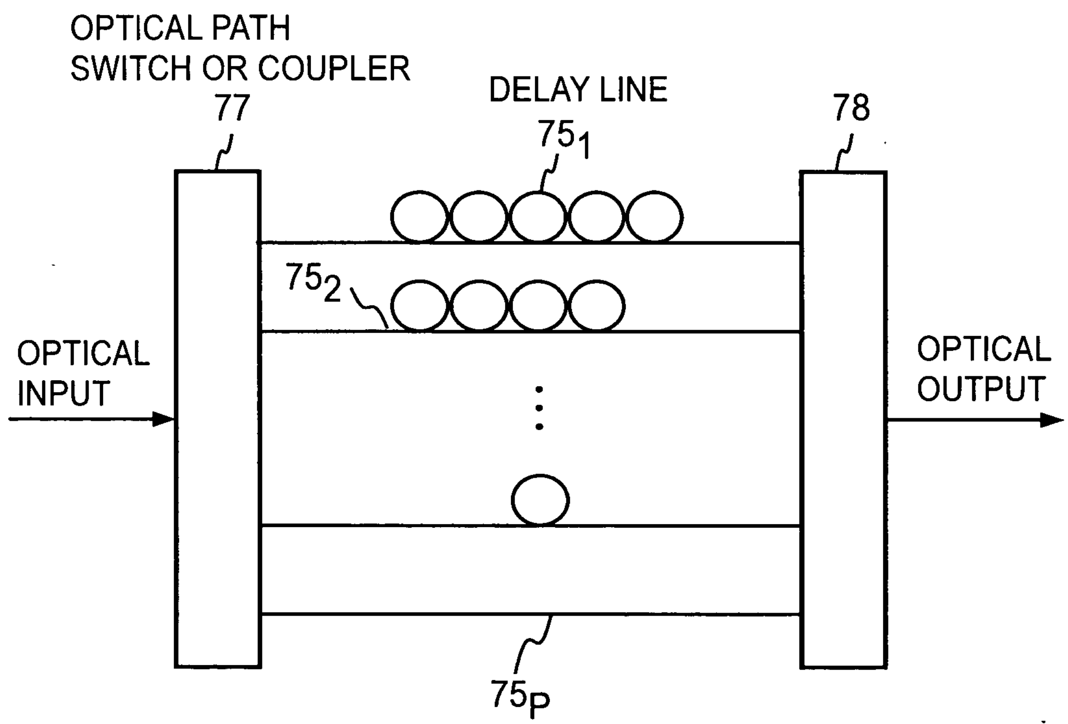
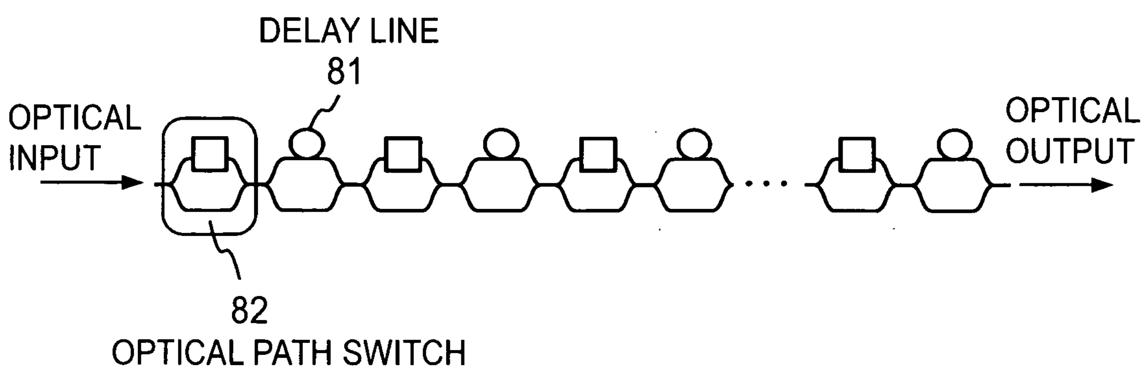

OPTICAL PATH
SWITCH OR COUPLER
77
DELAY LINE
75_1
78
75_2
OPTICAL
INPUT
OPTICAL
OUTPUT
75_P

FIG. 19


DELAY LINE
81
OPTICAL
INPUT
OPTICAL
OUTPUT
82
OPTICAL PATH SWITCH

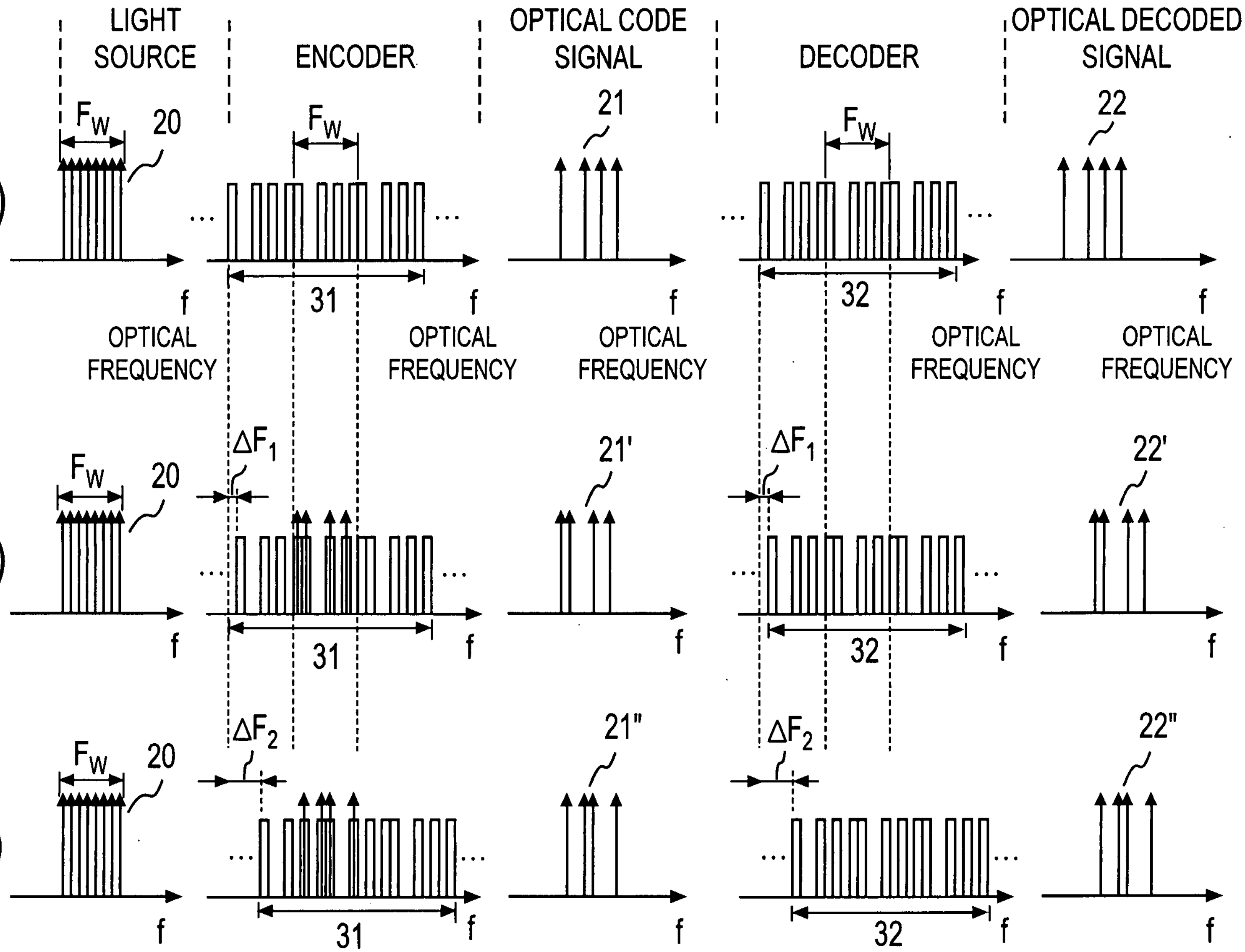
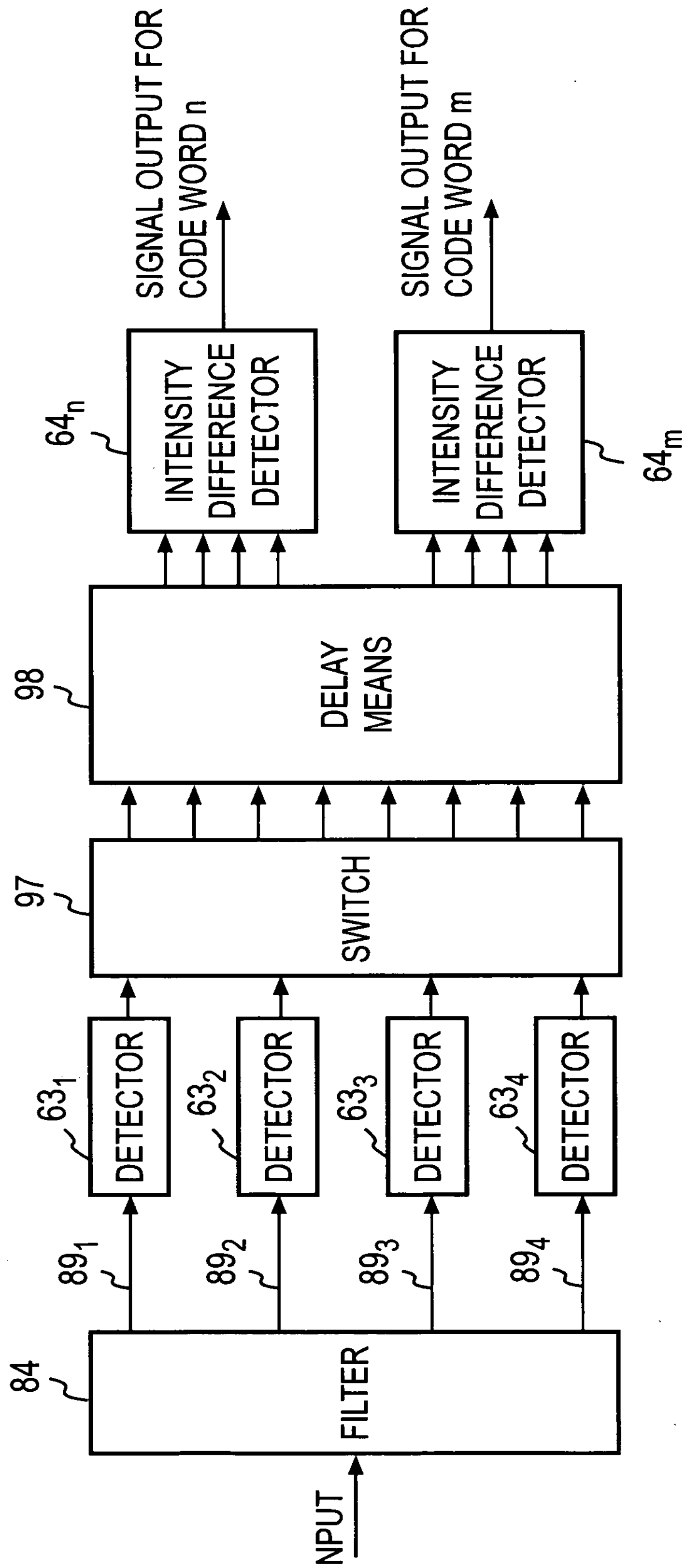


FIG. 20(a)

FIG. 20(b)

FIG. 20(c)



SIGNAL OUTPUT FOR CODE WORD n
SIGNAL OUTPUT FOR CODE WORD m
64_n
INTENSITY DIFFERENCE DETECTOR
INTENSITY DIFFERENCE DETECTOR
64_m
98
DELAY MEANS
97
SWITCH
63_1
DETECTOR
63_2
DETECTOR
63_3
DETECTOR
63_4
DETECTOR
89_1
89_2
89_3
89_4
84
FILTER
INPUT

FIG. 27

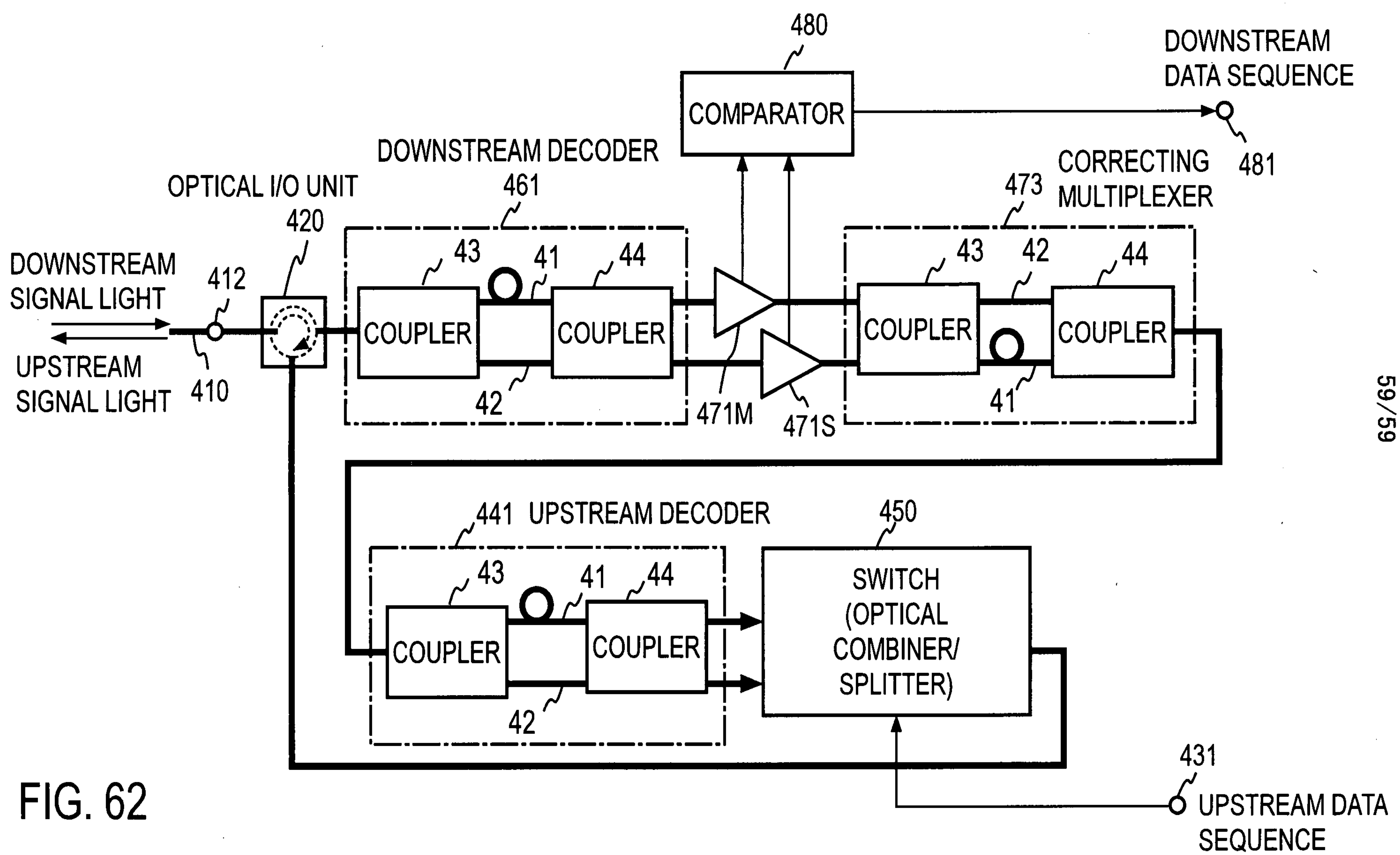

480
COMPARATOR
DOWNSTREAM
DATA SEQUENCE
481
DOWNSTREAM DECODER
461
OPTICAL I/O UNIT
420
CORRECTING
MULTIPLEXER
473
DOWNSTREAM
SIGNAL LIGHT
UPSTREAM
SIGNAL LIGHT
412
410
43
41
44
42
COUPLER
COUPLER
471M
471S
43
42
44
41
COUPLER
COUPLER
441
UPSTREAM DECODER
450
43
41
44
42
COUPLER
COUPLER
SWITCH
(OPTICAL
COMBINER/
SPLITTER)
431
UPSTREAM DATA
SEQUENCE

FIG. 62